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JOURNAL OF THE IRON AND STEEL INSTITUTE

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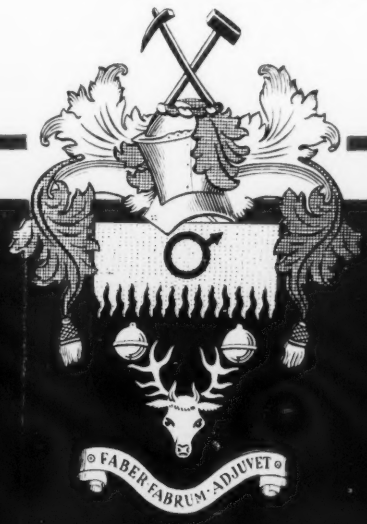

VOL. 170 PART 4

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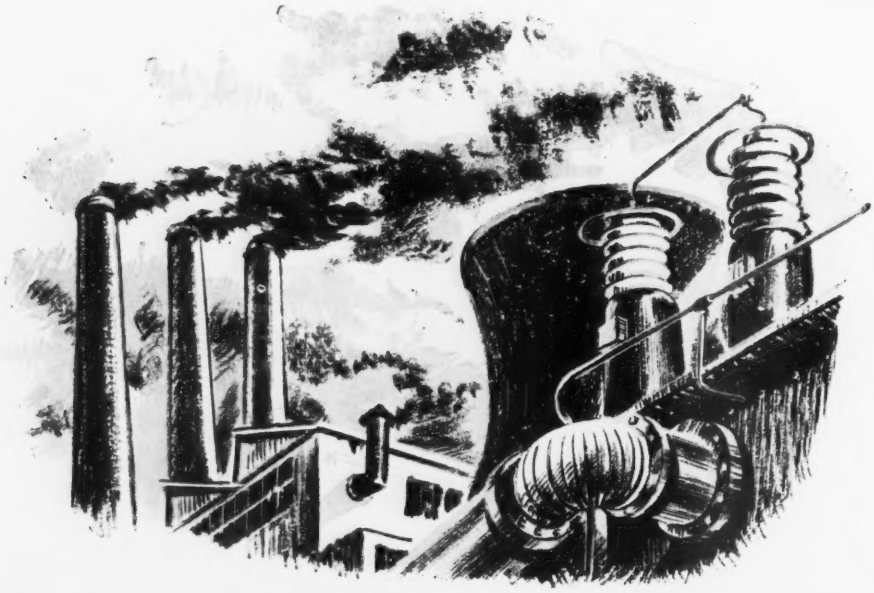

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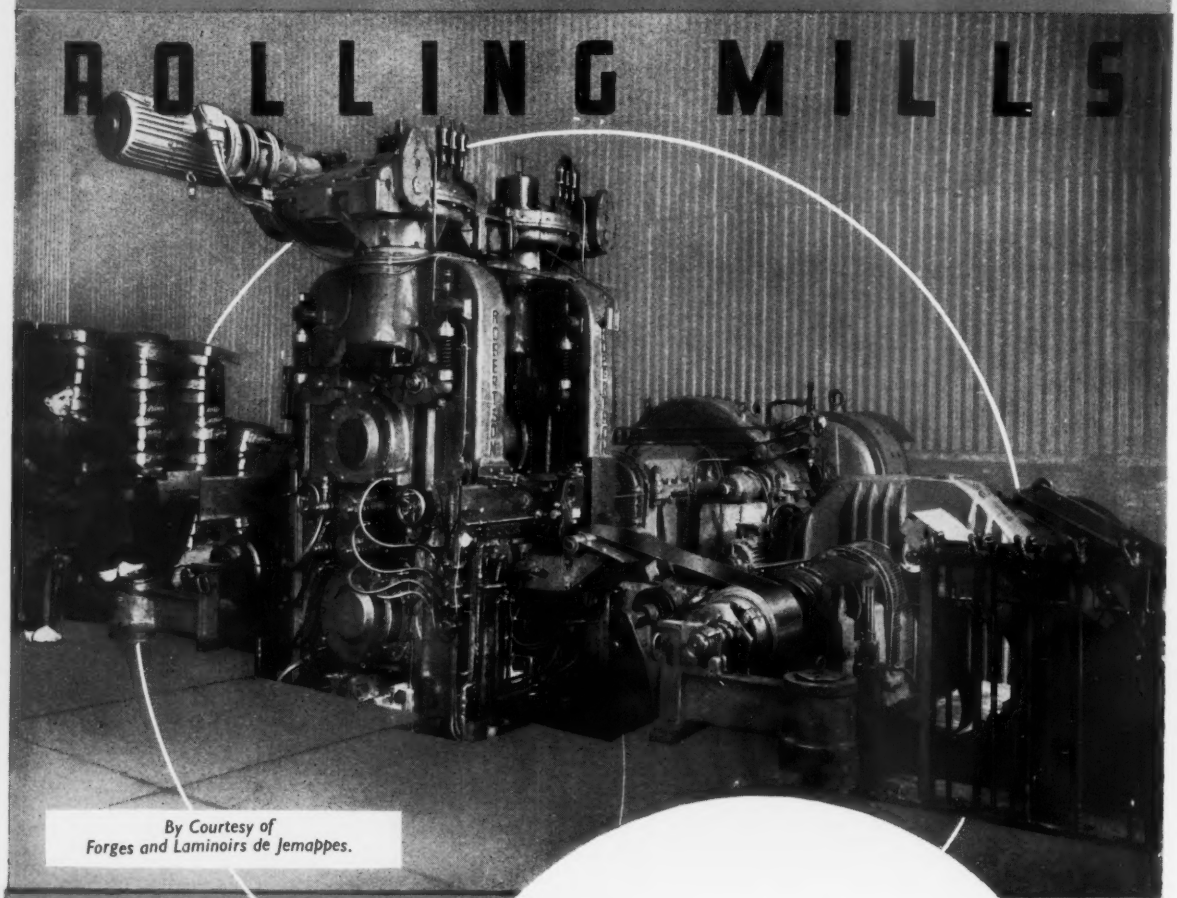

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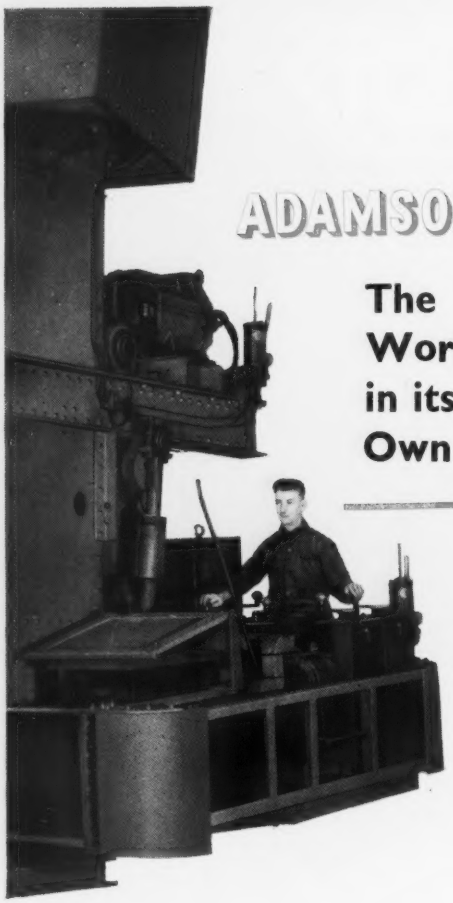

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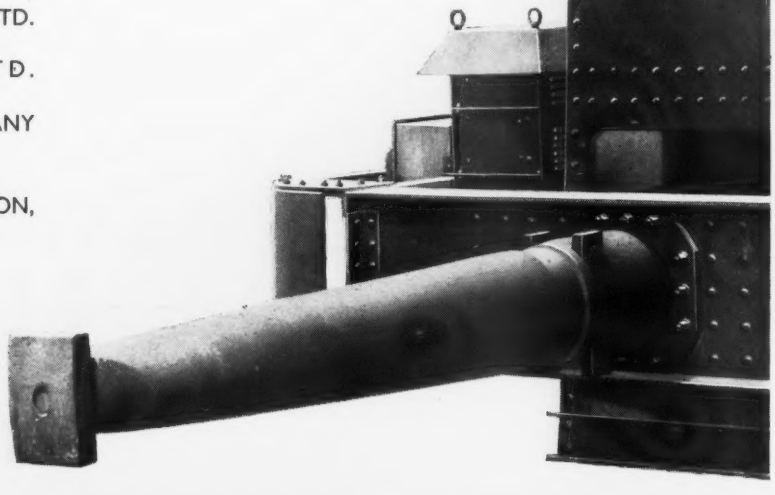

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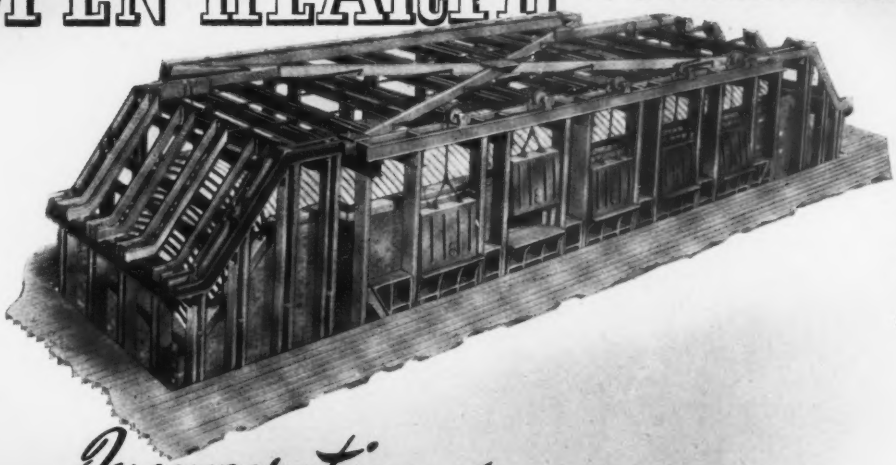

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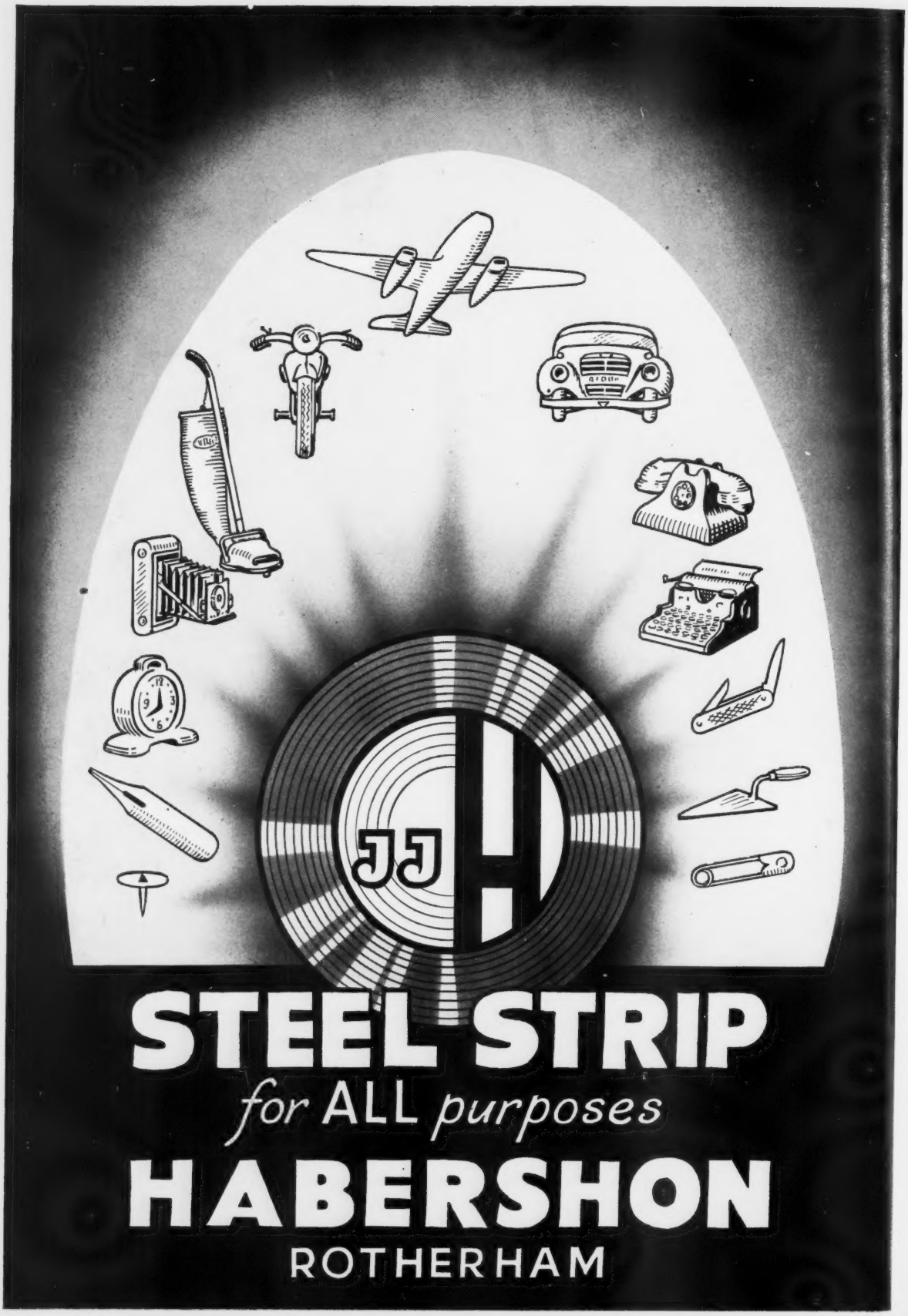
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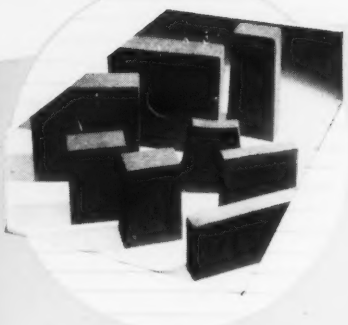

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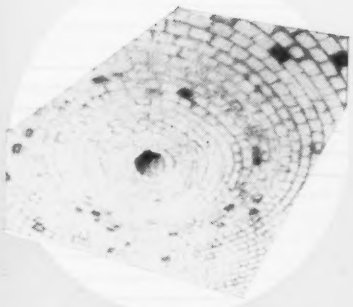

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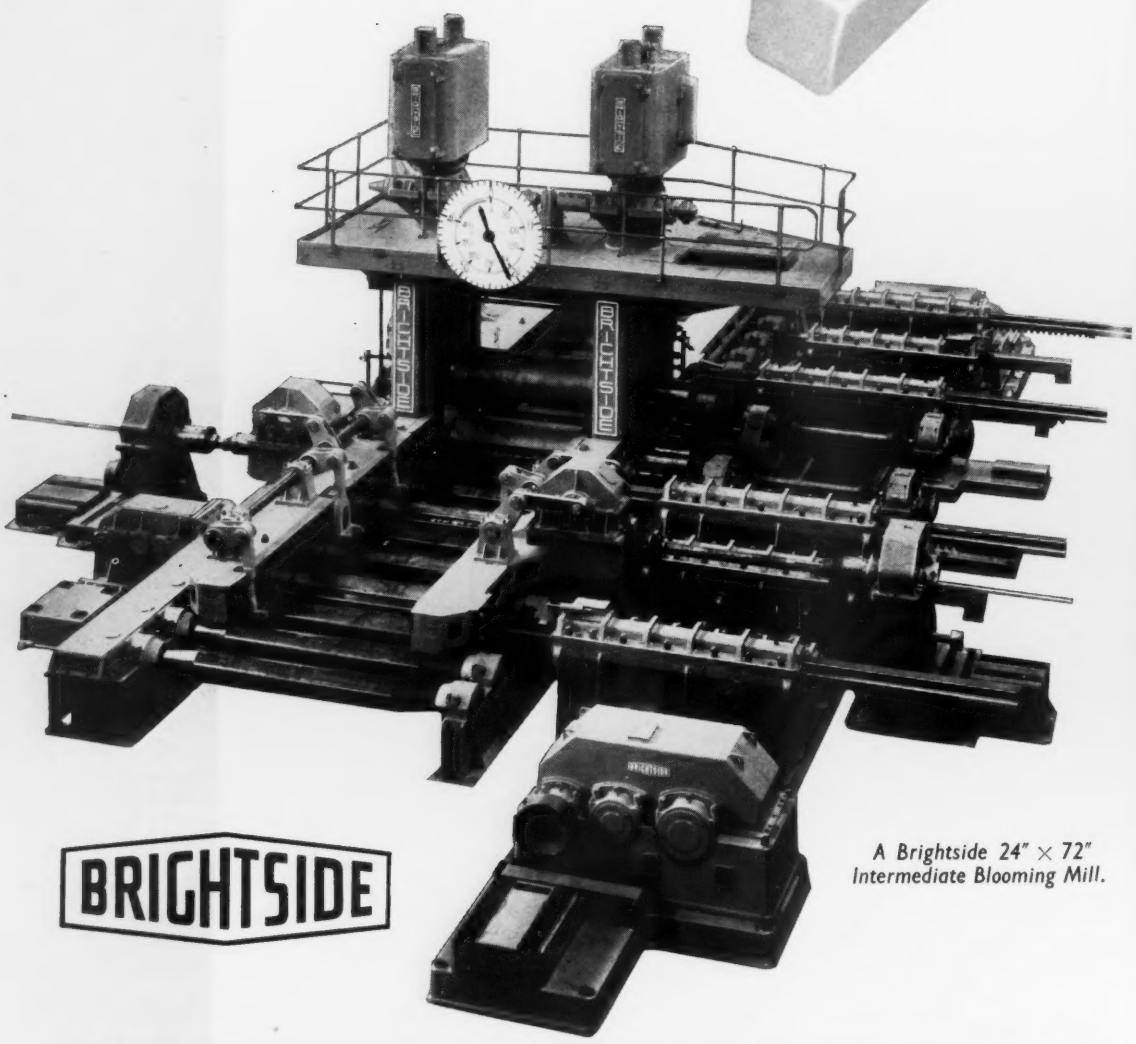

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BEETLE IN USE No. 15

This is the fifteenth in a series of announcements describing the actual experience of well-known foundries using Beetle Resin W20 in production quanties.

Part of the plant layout for producing vehicle parts at the Daimler Foundry.

"W20 SPEEDS URGENT JOB"

Production of cores was tripled by the use of Beetle W20 and a tunnel type oven built for the job, thus making possible the fulfilment of an urgent order. The photograph shows a line of cores which are fed four at a time into the oven (at left). Over 250 such cores can be stoved in an eight-hour working day.

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Economical yet efficient protection of steelwork often provides a headache for maintenance engineers. The remedy is simple. It lies in the use of two products of British Paints Limited. MIRACULUM GRAPHITE PAINT, for use where decorative effect is unnecessary, keys thoroughly into the metal and is sufficiently flexible to withstand expansion, contraction and vibration. It is unsurpassed for use in industrial areas and tropical climates because noxious atmospheres and extremes of temperature cannot affect it. Structures painted with Miraculum Graphite Paint remain corrosion-free for twice as long as with ordinary protective paints.

SUPERLATIVE BRIDGE PAINT for use where appearance is important, gives a hard mirror-smooth gloss that does not peel or crack. It is completely water and weather resistant and gives a 7-year protection under the worst conditions. Its durability is a byword.

For a complete treatment of structures, Dampney's Three Coat Treatment is recommended. This consists of a priming coat of Miraculum Red Lead Filler, a coat of Miraculum Graphite Paint and a final coat of Superlative Bridge Paint.

You are invited to consult our Technical Division on protection problems.

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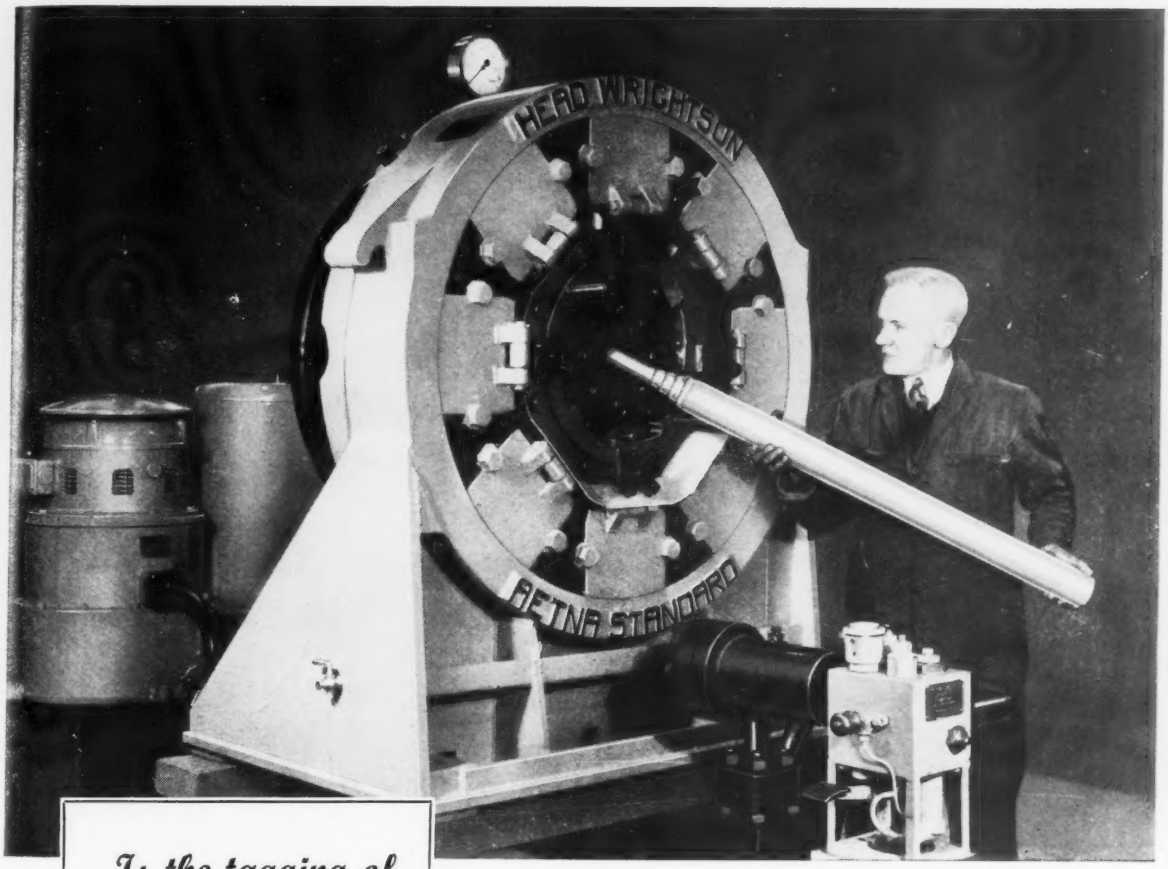
19B

THE COLD DRAWING OF TUBES

- POINTING by HEAD, WRIGHTSON



Is the tagging of tubes one of your problems?

IF SO, HERE IS THE ANSWER!

The Squeeze Pointer illustrated is capable of pointing steel or non-ferrous tubes in readiness for cold drawing. This unit will deal with tubes up to 6" outside diameter and produce 100 points per hour with a maximum diameter difference of 1¾". All non-ferrous tubes and most steel tubes are pointed cold.

Note the following features:

1. Hollow Concentric Points. 2. Shouldering for mandrel drawing. 3. No vibration. 4. Quiet operation. 5. Heating of tubes unnecessary.

For Squeeze Pointers, Push Pointers, Cold Drawing Benches, etc., consult—

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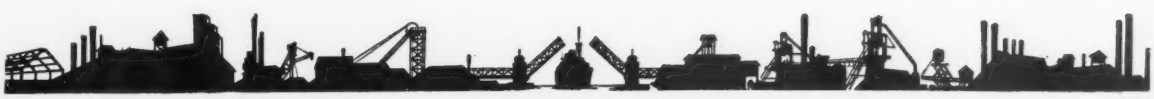

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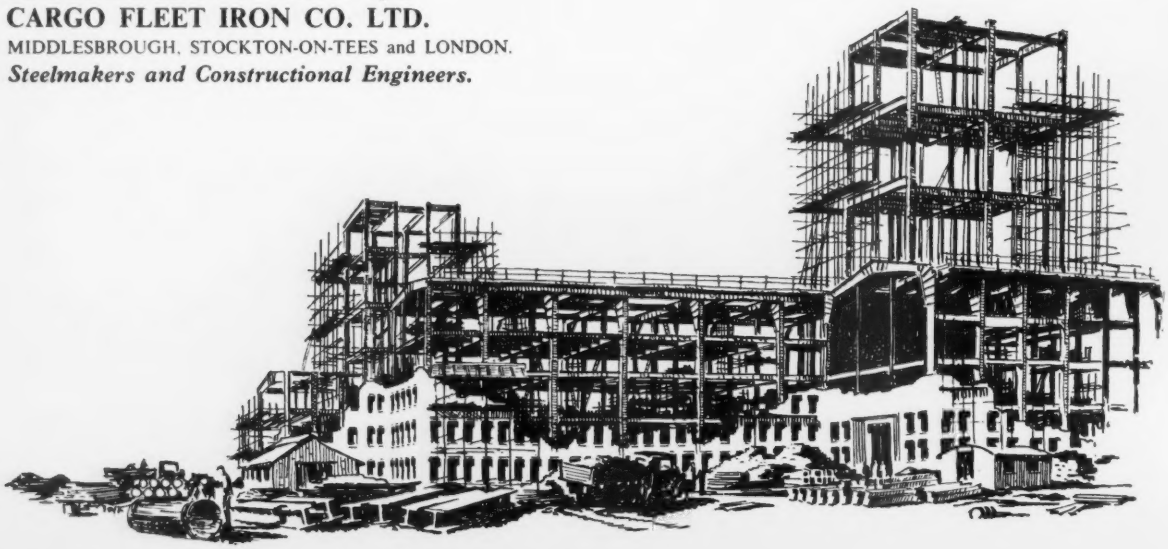

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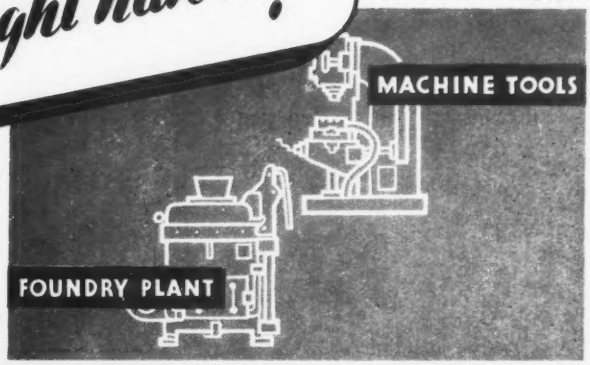

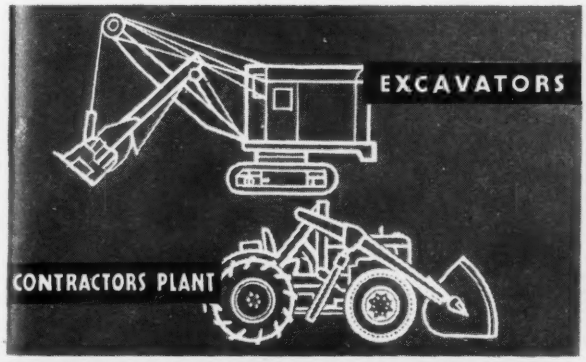

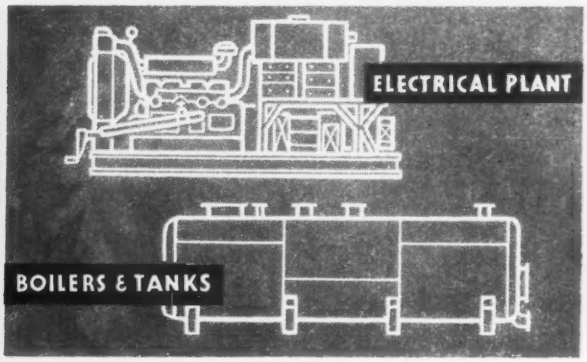

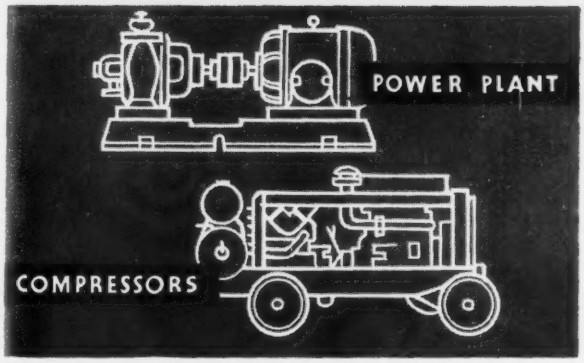

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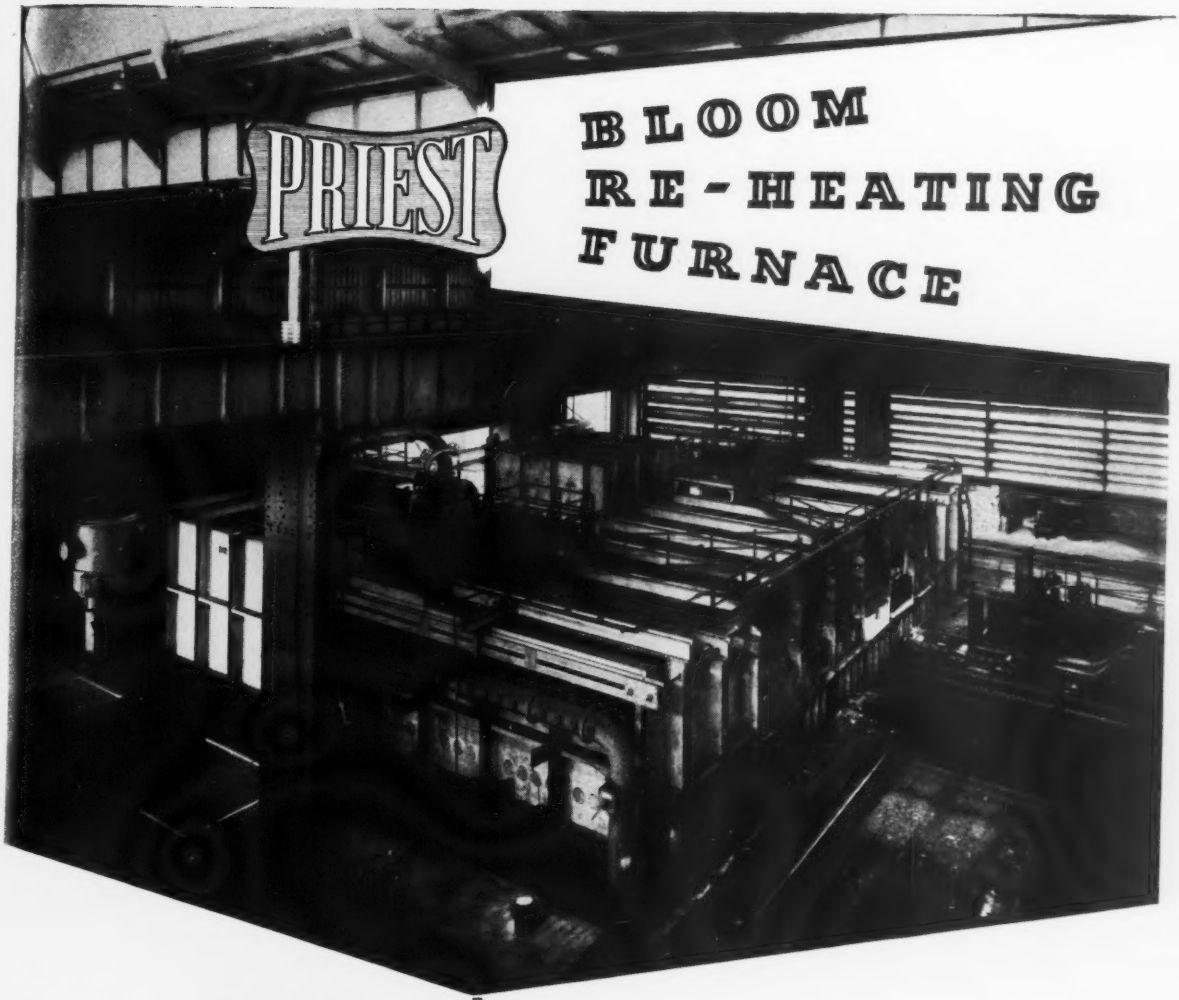

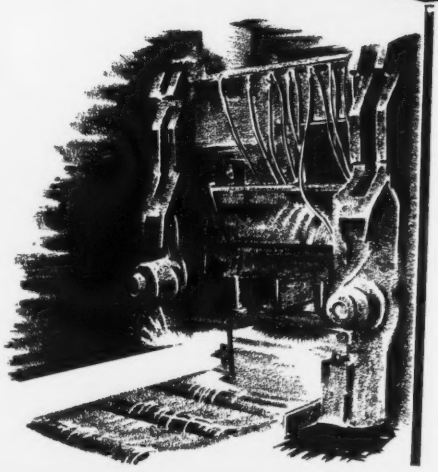

This Bloom Re-heating Furnace installed at a large steelworks in Lincolnshire provides a throughput rate of 60 tons per hour when re-heating 6" blooms 20' 0" long to 1340°, for a fuel consumption of less than 5 therms per ton.

The furnace hearth is 25' 0" deep and 49' 0" long with six electrically operated doors 6' 3" wide, water-cooled door lintels and fitted jambs. The furnace is of the reversing type with Priest suspended roof, patent multipass air regenerators and needle type gas recuperator.

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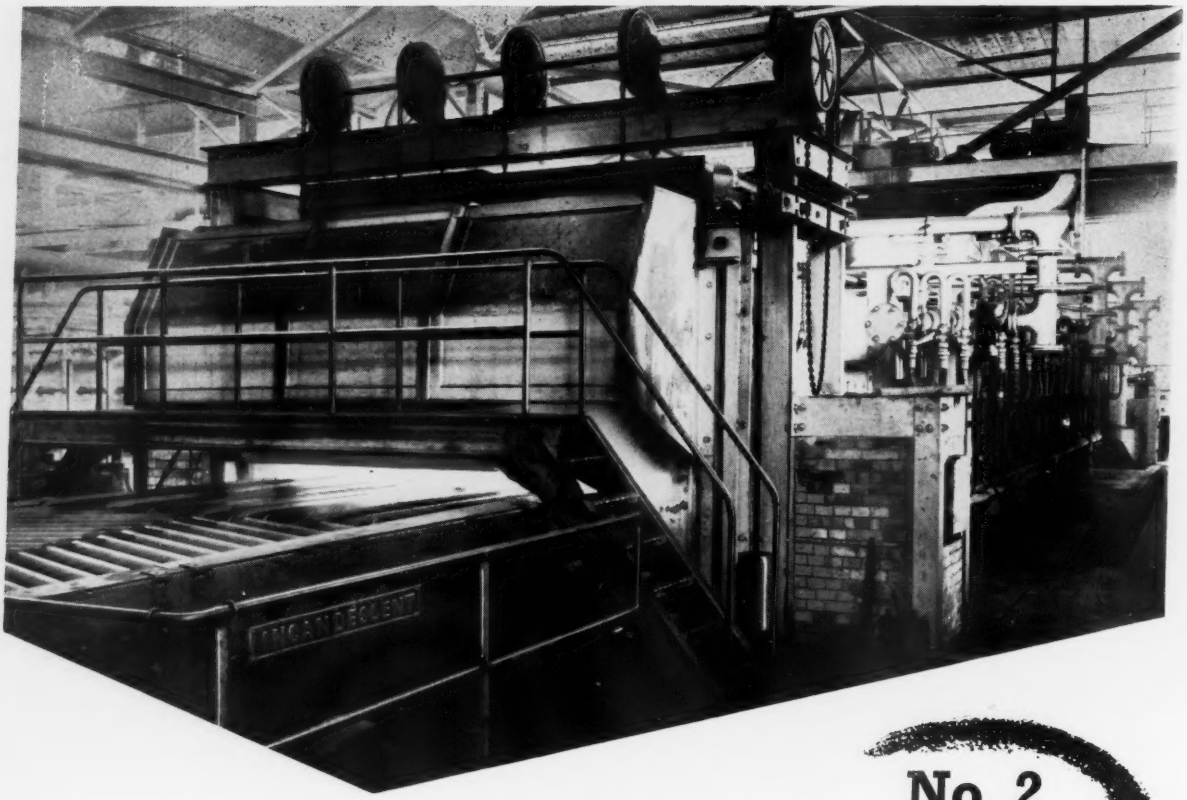
F20

WALKING BEAM FURNACES IN INDUSTRY



No. 2 PACK HEATING

In many of the world's leading Sheet Mills, packs are heated by Incandescent Walking Beam Furnaces.

The unit illustrated is a hydraulically operated walking beam furnace installed in a large Swedish sheet mill. It is used for heating both low carbon and stainless steel packs which are discharged to the herringbone conveyor in the left foreground for conveyance to a mechanised two-high mill. The high quality sheets produced by this Swedish company are helping to satisfy the heavy demand for sheets with superior deep drawing and manipulative qualities for use in automobile and other industries where material of the highest quality is essential

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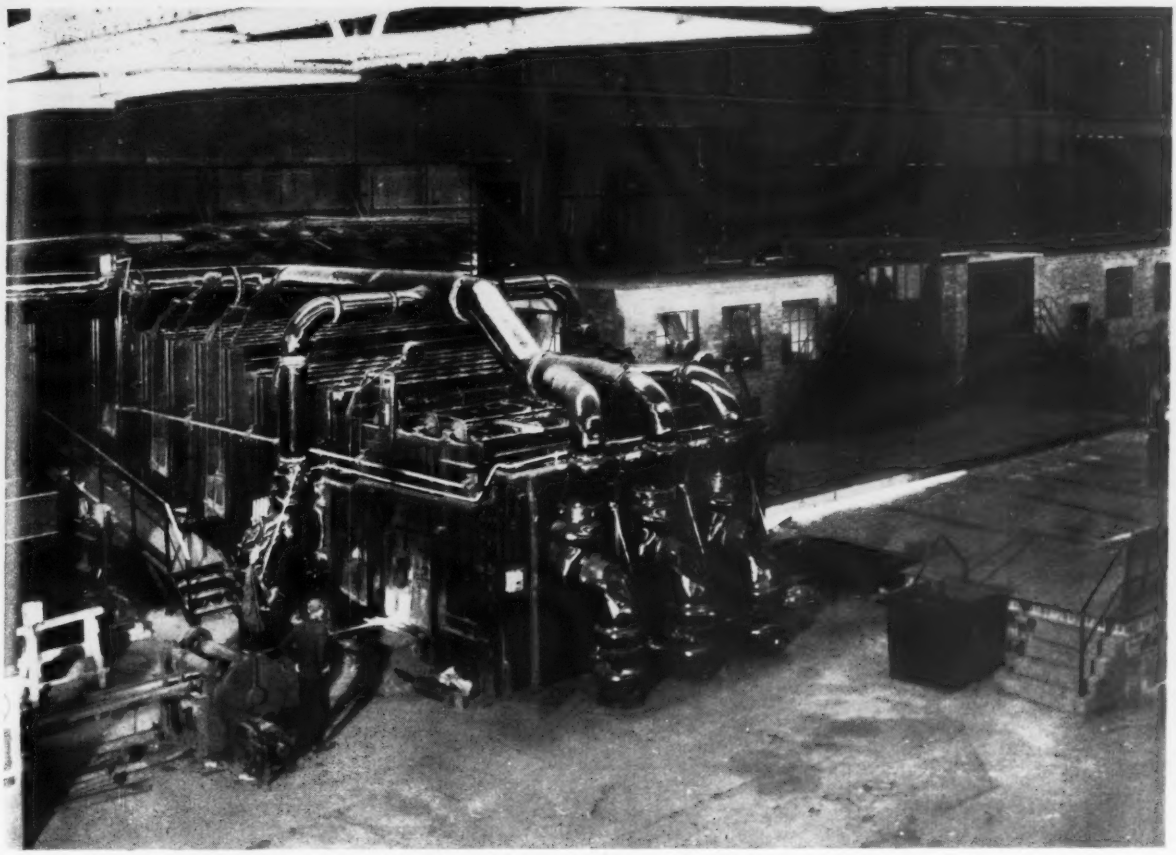

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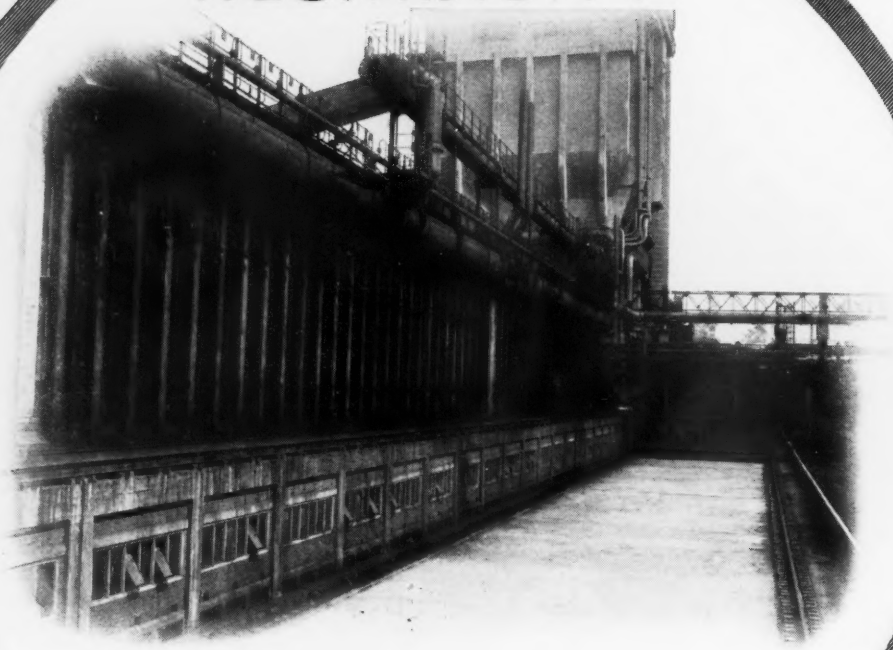

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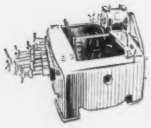

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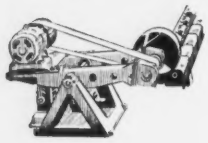

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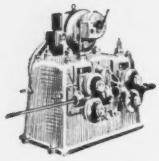
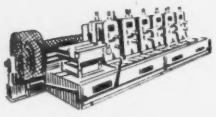


Close Joint Tube Forming Machines in three sizes from ½″ to 5″ diameter tube.



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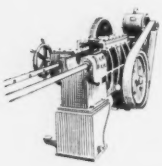

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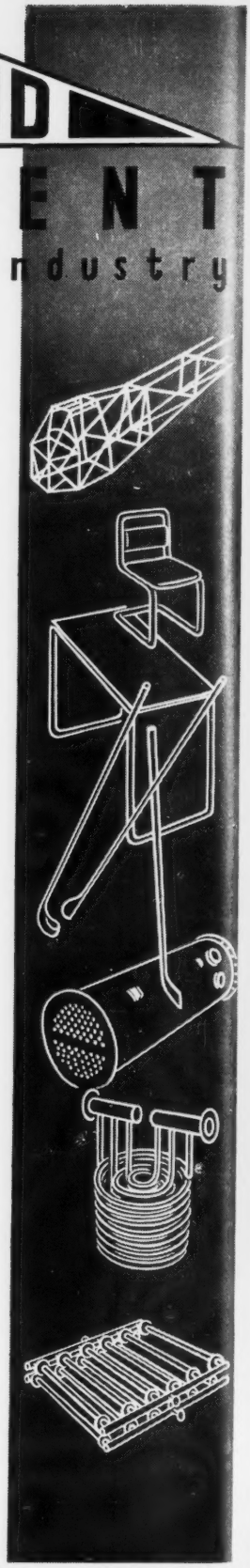

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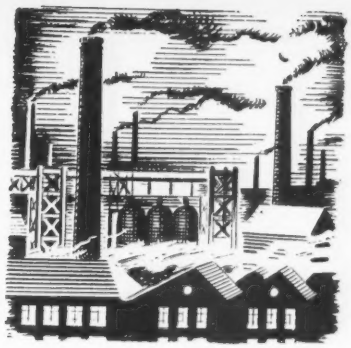

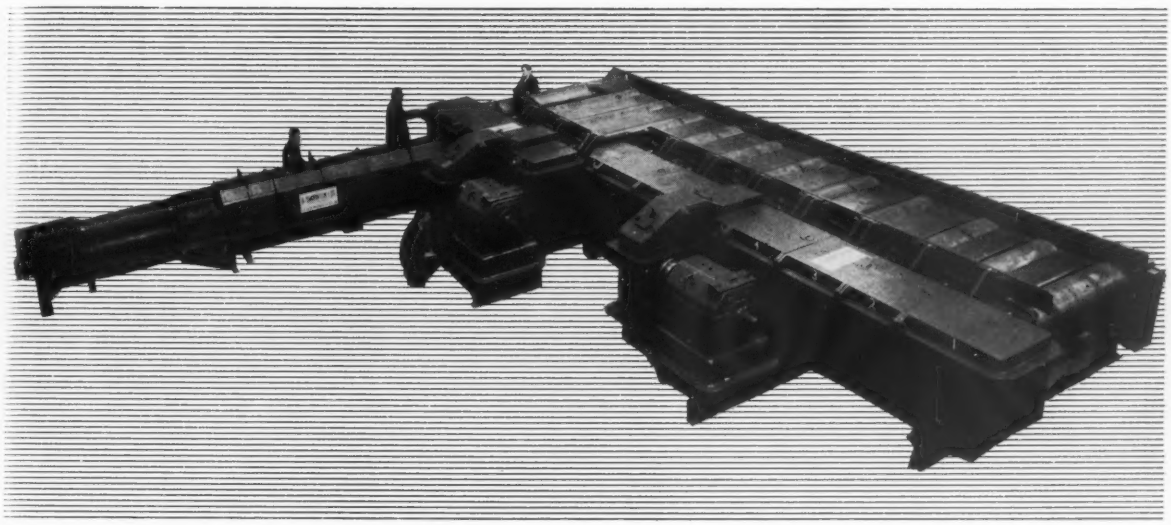

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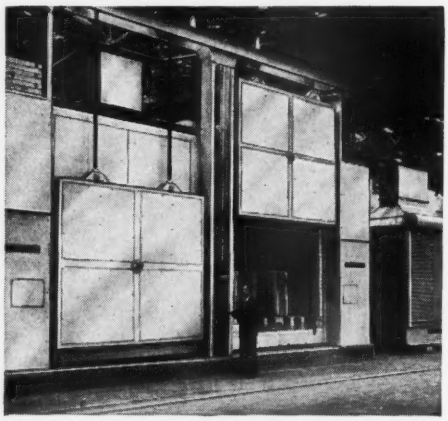

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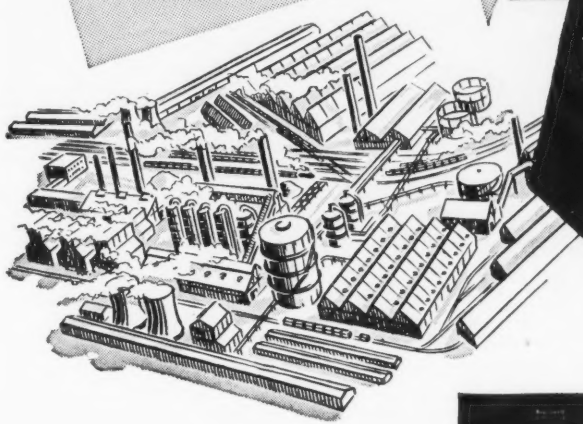

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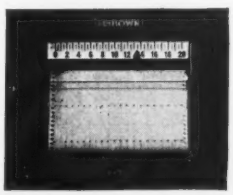

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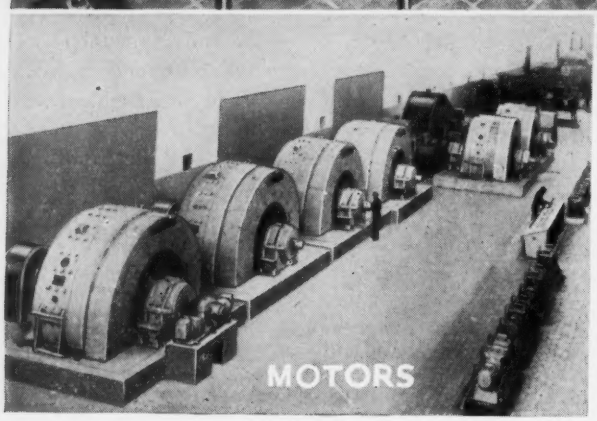

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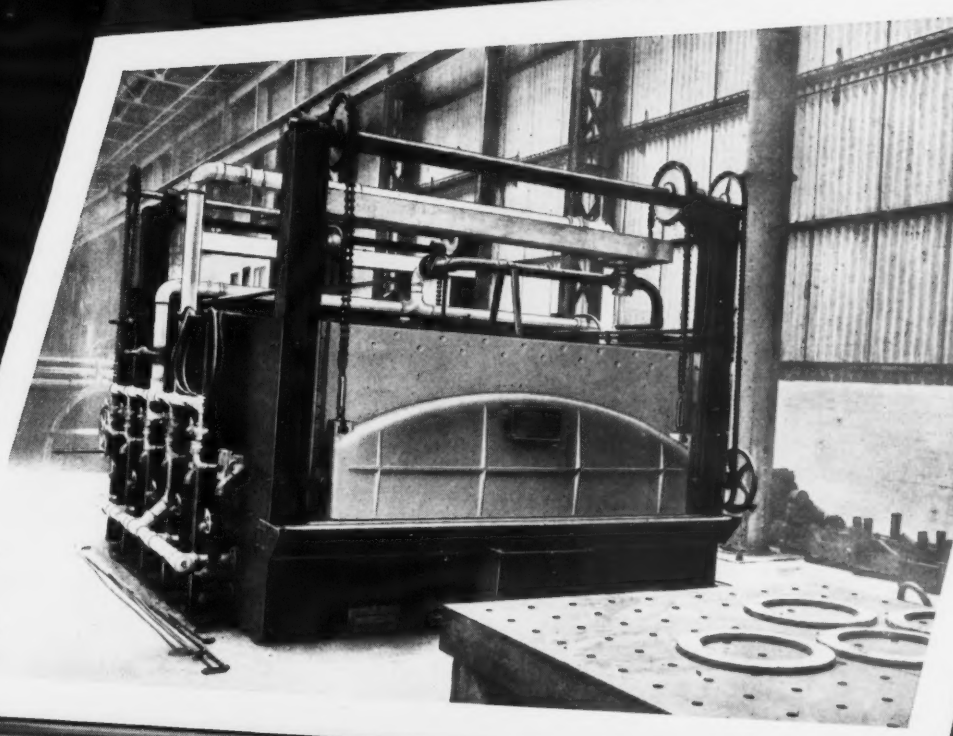

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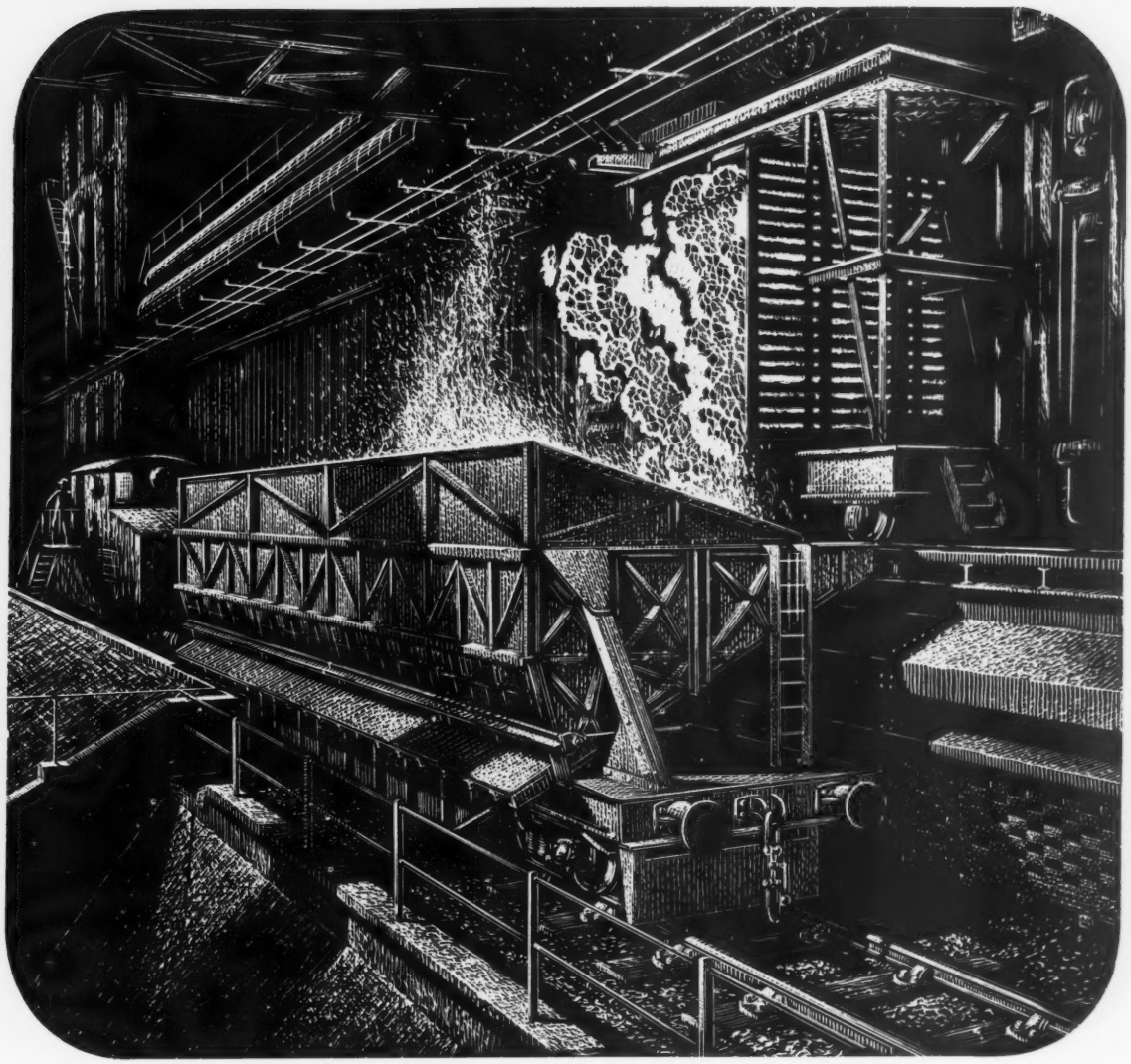

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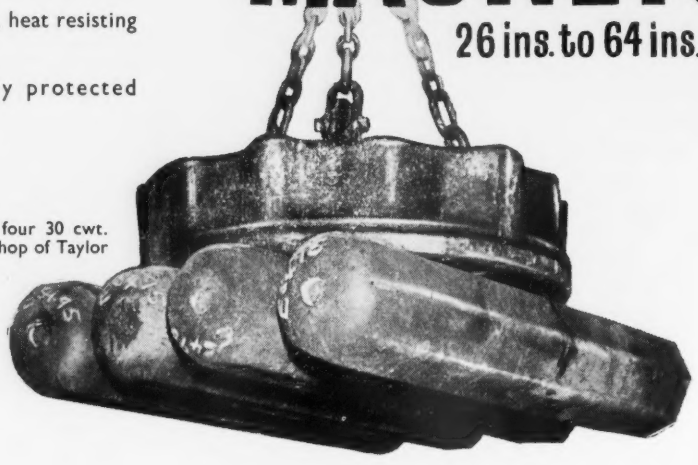

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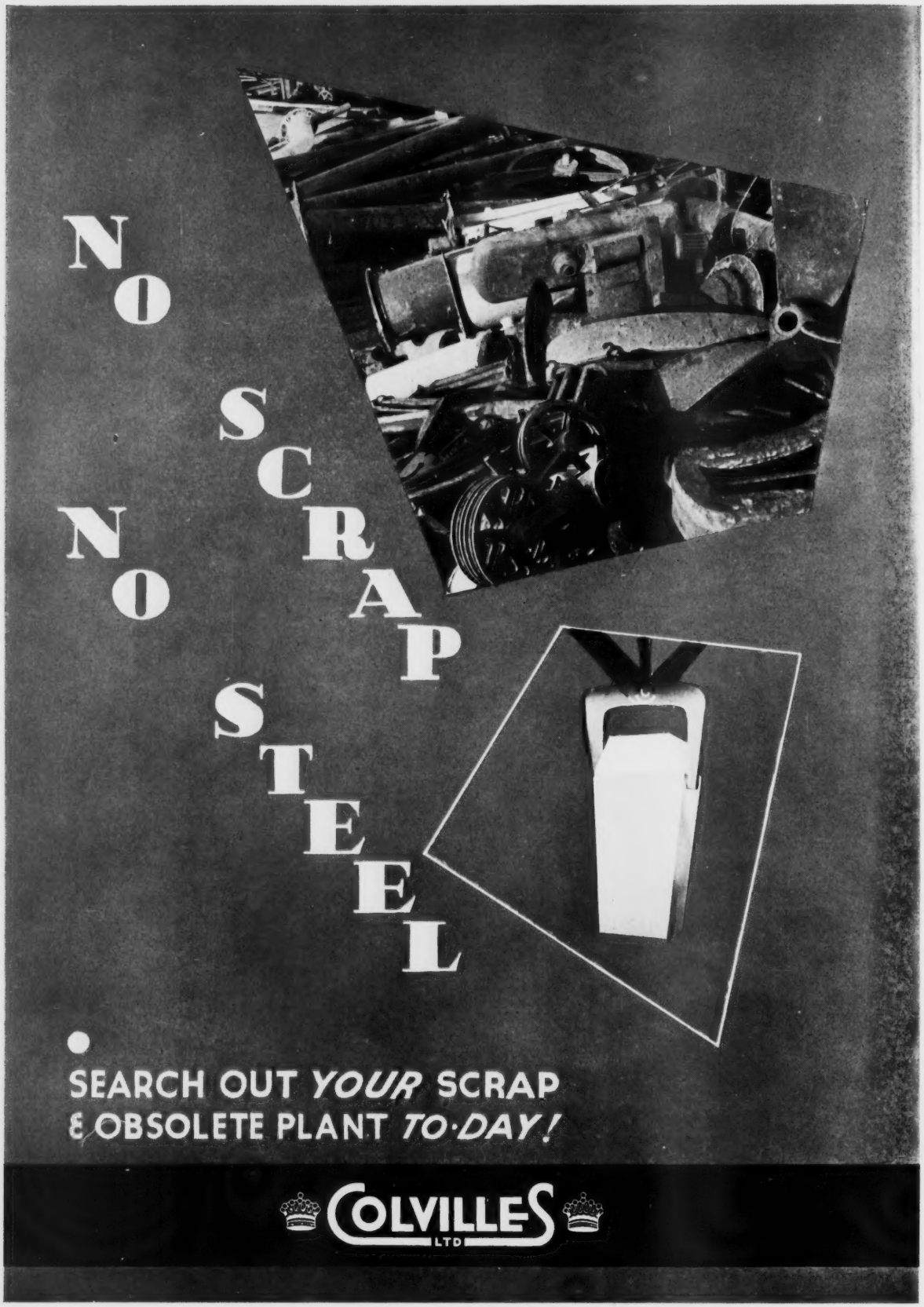

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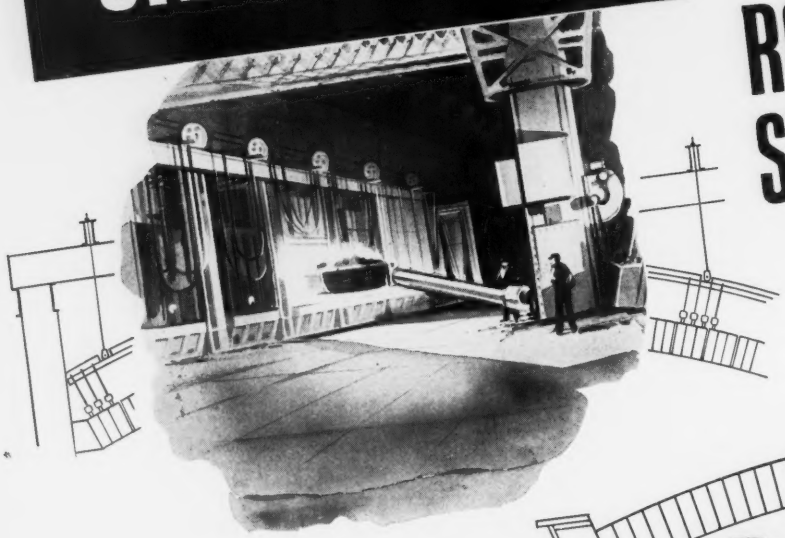

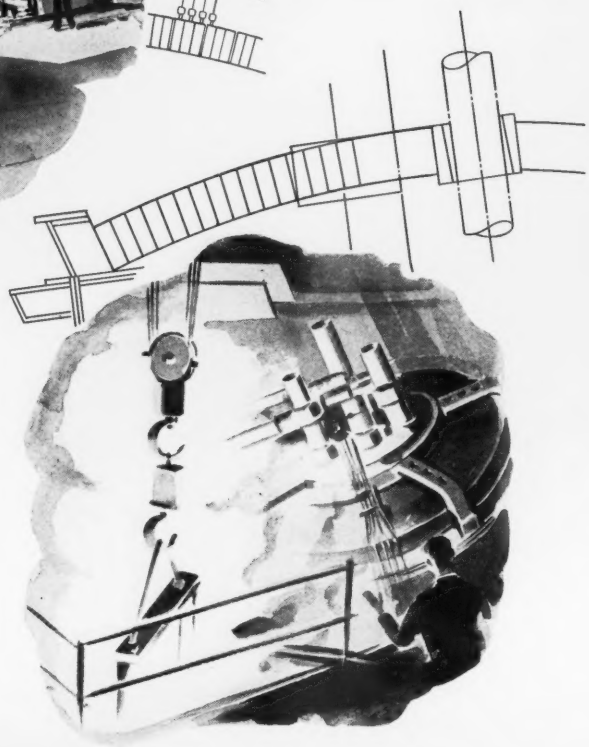

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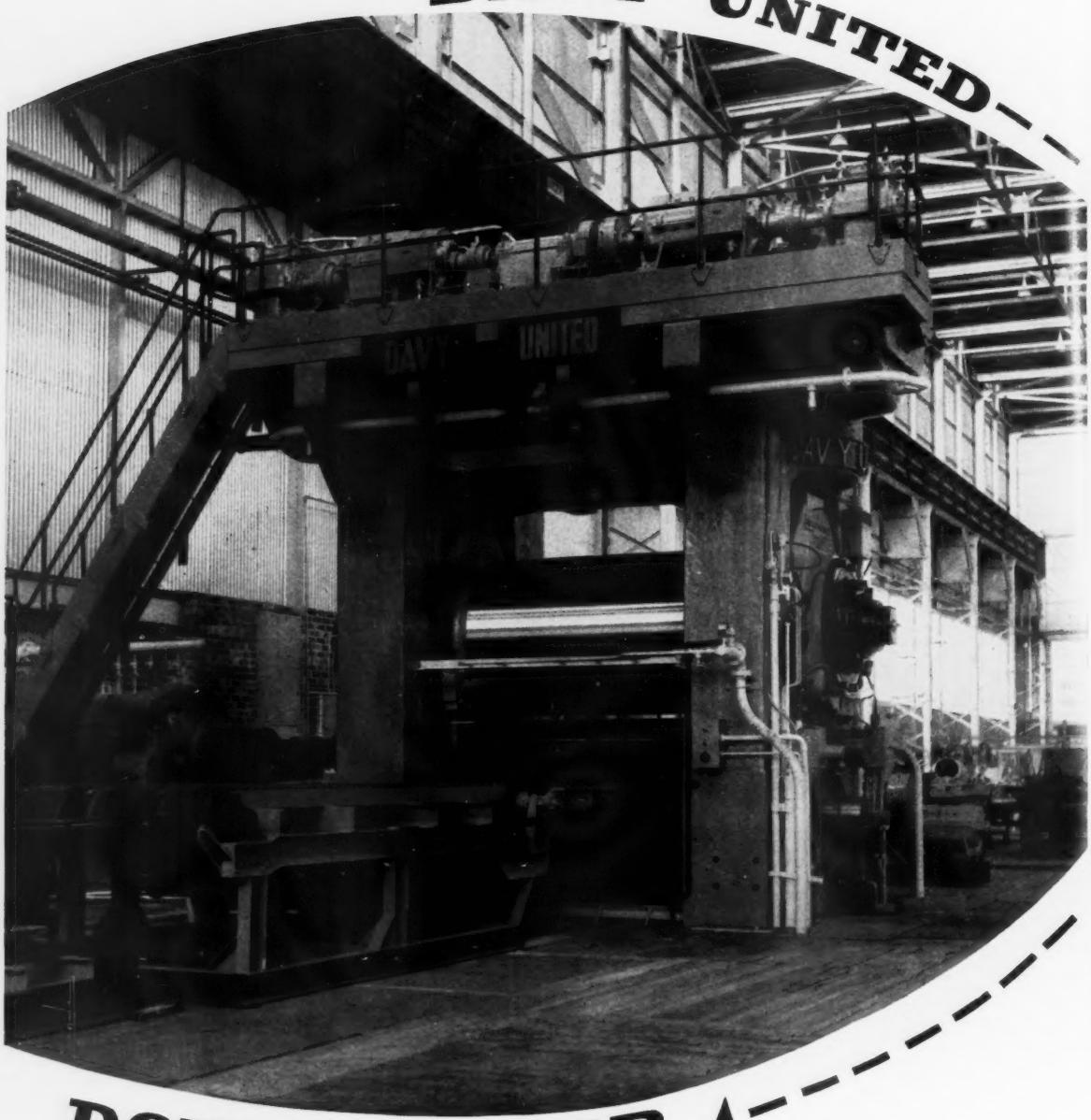

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HERBERT HENRY BURTON, C.B.E., F.I.M.

HERBERT HENRY BURTON, who is Director of Metallurgy and Research at the English Steel Corporation, Limited, Sheffield, was educated at Sheffield Royal Grammar School and King Edward VII School and at Sheffield University.

He first joined the staff of the Research Department of Messrs. Cammell, Laird and Company, where he was responsible for a number of investigations, both in the laboratory and in the works. He later became Assistant Superintendent of the Department. After the formation of the English Steel Corporation, Limited, in 1929, Mr. Burton was appointed Senior Assistant to the late Mr. J. H. S. Dickenson, and succeeded him as Chief Metallurgist upon his death in 1934. He was appointed a Special Director of the Company in 1938, and a Director in 1943. Mr. Burton is also a director of Firth-Vickers Stainless Steels Limited, of Darlington Forge, Limited, and of Industrial Steels, Limited.

Mr. Burton was for many years a member of several Joint Committees of The Iron and Steel Institute and the Iron and Steel Industrial Research Council, becoming Chairman of the Ingots Committee and of the Hair-line Crack Sub-Committee on the death of Dr. Swinden. Those Committees now form part of the British Iron and Steel Research Association, of which he is a member of Council, and a member of the Metallurgy Divisional Panel. He is also Chairman of the Alloy Steels Research Committee, the Forging Committee, and the Inclusions Committee. During the war he was appointed Chairman of the Technical Sub-Committee dealing with gun forgings, and was also a member of the Gun Design Committee, the Metallurgy Committee of the Advisory Council on Scientific Research and Technical Development, the Technical Advisory Committee of the Special and Alloy Steel Committee, and many others. He carried out extensive investigations in connection with steels for guns, tanks and aircraft armour, and steels for aero-engines. He was a member of the Delegation to the U.S.A. in 1943 in connection with the conservation of alloys in steel manufacture.

When the Inter-Services Metallurgical Research Council was formed after the end of the war, Mr. Burton was appointed a member of Council, and also the first Chairman of the Ferrous Metals Committee, which is one of the main branches of the Council's activities. Mr. Burton has taken an active part in problems arising from the re-armament plan and the steps which have been taken to conserve scarce alloying elements. He was appointed Chairman of the Alloy Steel (Rearmament) Technical Committee, formed in 1951, and is also a member of the recently formed Metals Economy Committee of the Ministry of Supply.

Apart from these appointments on various committees, Mr. Burton is an Associate Member of the Ordnance Board, a member of the General Board of the National Physical Laboratory, and a member of the Court of Governors and of the Advisory Committee on Engineering and Metallurgy of Sheffield University. He was elected a Member of The Iron and Steel Institute in 1935 and became a Member of Council in 1944. In 1947 he was elected a Vice-President, and in April of this year (1952) he is to be awarded the highest honour bestowed by the Institute, the Bessemer Medal, for his distinguished services to the steel industry and to metallury, with particular reference to the development of alloy steels and of heavy forgings.

H. H. Burton, C.B.E., F.I.M.
Bessemer Medallist, 1952

IRON AND STEEL
INSTITUTE PAPERS

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Application of the Isothermal Transformation Diagram to the Normalizing of En 40C Steel

By J. A. Cameron, B.Sc.

SYNOPSIS

The quantitative application of the isothermal transformation diagram of a 0·4% carbon, 3% chromium steel, has been investigated with reference to the normalizing of large forgings. It is found that the cooling rate required to avoid transformation in the pearlite range may be calculated from the isothermal data, but these data are of doubtful value for predicting the temperature required to complete transformation in the bainite range. The discrepancy between the isothermal and anisothermal data was investigated, and it has been found that about 25% austenite with a carbon content of about 1·2% may be retained at room temperature in specimens slowly cooled through the bainite range and water-quenched from above or below the M_s point. Part of this retained austenite is thought to be 'conditioned' so that it transforms on cooling from the tempering temperature.

Introduction

To avoid dangerous stresses, forgings with sections greater than 40 in. are often hardened by normalizing to about 300° C. and are immediately tempered without being allowed to go cold. The isothermal transformation diagram of the steel indicates in which temperature ranges rapid transformation is likely to occur. With a steel having the type of isothermal transformation diagram shown in Fig. 1, transformation in the pearlite range should be entirely suppressed if a high level of hardness is required. For the tempering to be wholly effective, transformation in the bainite region should be completed before reheating for tempering. An attempt has been made to find how the isothermal transformation diagram may be used quantitatively to decide whether transformation will be avoided in the pearlite range and to determine the temperature to which the steel should be cooled for completion of the transformation in the bainite range. The cooling rate of the forging during normalizing may be determined experimentally, and if the critical cooling rate through the pearlite range can be calculated from the isothermal transformation diagram, it may be possible to predict whether transformation in the pearlite range will be suppressed.

A method for determining the beginning of transformation during cooling, using the isothermal transformation diagram, was first suggested by Scheil,[1] who postulated that transformation during cooling should begin when

$$\sum \frac{t_i}{t_b} = 1$$

where t_i is the time spent at a given temperature and t_b is the induction period at that temperature. Krainer,[2] using two-step treatments in the pearlite range, obtained results in reasonable agreement with Scheil's hypothesis. He found that transformation commenced at the lower temperature when

$$\sum \frac{t_i}{t_b} = 0{\cdot}95 \pm 0{\cdot}25.$$

Jaffe,[3] who also used two-step treatments in the pearlite range, confirmed Krainer's results, but in the bainite range his results did not support Scheil's hypothesis. Manning and Lorig,[4] using two-step treatments and continuous cooling, showed that the Scheil hypothesis was valid in the pearlite range, but not in the bainite range.

The present paper describes experimental work carried out to verify the hypothesis and to test the method suggested by Pumphrey and Jones[5] for following the course of transformation in the bainite range.

EXPERIMENTAL PROCEDURE

The material used in this work, although not the

Manuscript received 23rd March, 1951.
Mr. Cameron is at the Brown-Firth Research Laboratories, Sheffield.

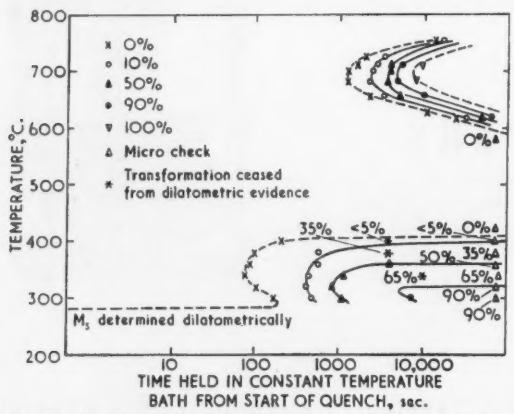


Fig. 1—Isothermal transformation diagram of a 0·4% C, 3% Cr steel

same as that employed for large forgings, had a similar composition and similar transformation characteristics. The steel was melted in the basic electric-arc furnace, and rolled to $\frac{5}{8}$-in. dia. rod, of the following analysis : 0·41% C, 0·29% Si, 0·63% Mn, 0·006% S, 0·011% P, 0·24% Ni, 3·43% Cr, 0·97% Mo, 0·20% V. A fixed austenitizing treatment of 30 min. at 940° C. dissolved essentially all the carbides. The austenitic grain size was A.S.T.M. 8.

A dilatometer similar to that used by Allen, Pfeil, and Griffith[6] was employed, and a microscopic check for completeness of transformation of the dilatometer specimen was used to calibrate the dilatometric indications of the progress of transformation.[7] The dilatometer specimens (0·110 in. dia. × 1·14 in. overall length with a 120° cone at each end) were plated with a thin film of nickel to reduce decarburization effects during austenitizing. The metallographic estimate of the amount of transformed or untransformed product was the mean estimate of two observers.

Cobalt Kα radiation was used in all the X-ray work. The surface of the solid X-ray specimen was inclined at an angle of about 20° to the direction of the X-ray beam and the reflections were recorded on a cylindrical film, over a range of Bragg angles of about 10–80°. The X-ray estimates of retained austenite were obtained by comparing the reflections with powder photographs of mixtures containing 5, 10, 20, and 30% by weight of an austenitic steel and pure iron. The method gives an estimate of the austenite present to the nearest 5%.

The carbon content of the retained austenite was obtained from lattice parameter measurements.[8] The usual extrapolation method was not considered satisfactory because the high-angle reflections of the austenite were weak. A sufficiently accurate measurement of the Bragg angle of low-order reflections was made possible by coating the surface of the specimen with a standard powder (tungsten). It is considered that the spacing measurements are accurate to about 1 part in 500, corresponding to an error of about 0·2% in the carbon content of the austenite.

Table I

AMOUNT OF AUSTENITE INDUCTED AT VARIOUS TEMPERATURES

Temperature, Range, °C.	Mean Temperature, °C.	t_b at Mean Temperature (from Fig. 1), sec.	Amount Inducted at Mean Temperature, $\left(\frac{t_i}{t_b}\right) \times 10^{-5}$
750–730	740	4200	24 t_i
730–710	720	1800	55 t_i
710–690	700	1300	77 t_i
690–670	680	1300	77 t_i
670–650	660	2000	50 t_i
650–630	640	5000	20 t_i
630–610	620	14,000	7 t_i
610–590	600	30,000	3 t_i

THE PEARLITE RANGE

Calculation of Critical Cooling Rate

Using the isothermal data in Fig. 1, the critical cooling rate through the pearlite range was calculated from Scheil's hypothesis. The range 750–590° C. was divided into steps of 20° C. and the amount of austenite inducted was calculated, as shown in Table I. The time, in seconds, required for the specimen to cool through 20° C. is denoted by t_i.

From Table I,

$$\sum \frac{t_i}{t_b} = 313 \times 10^{-5} t_i$$

$\therefore$ when

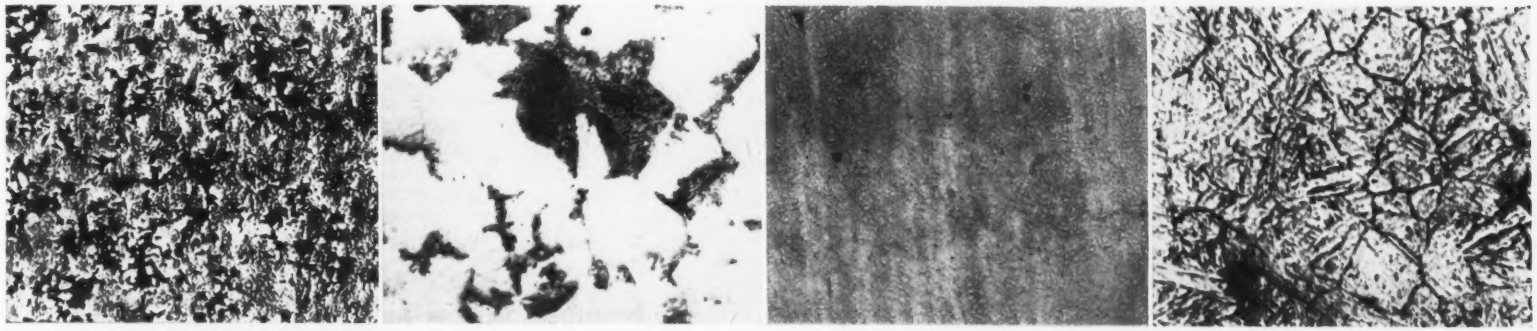
$$\sum \frac{t_i}{t_b} = 1, \; t_i = 320 \text{ sec.}$$

Table II

DETAILS OF COOLING TESTS

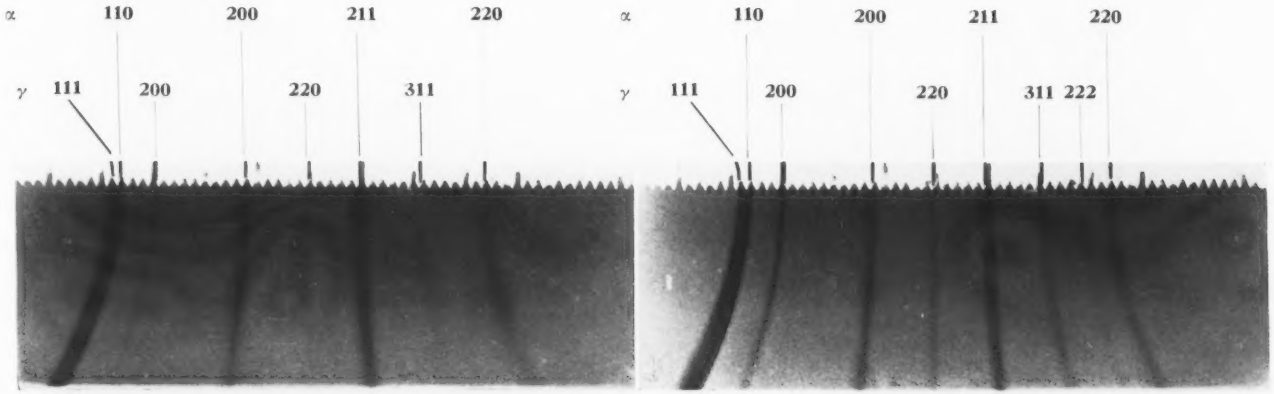
Temperature Range, °C.	Mean Temperature, °C.	t_i,* Time Spent at Mean Temperature, sec.	t_b, sec. (from Fig. 1)	Proportions Inducted at Mean Temperature, $\frac{t_i}{t_b}$	$\sum \frac{t_i}{t_b}$
At 750	750	960	13,500	0·07	
750–730	740	480	4200	0·01	
730–710	720	360	1800	0·20	
710–690	700	300	1300	0·23	1·3
690–670	680	300	1300	0·23	
670–665	668	120	1900	0·06	
At 665	665	1020†	2000	0·51	
At 750	750	4680	13,500	0·35	
750–730	740	580	4200	0·14	0·81
730–708	719	570	1800	0·32	
At 708	708	‡			
At 750	750	4200	13,500	0·31	
750–730	740	460	4200	0·11	
730–710	720	300	1800	0·17	0·90
710–696	703	210	1400	0·15	
At 696	696	210†	1300	0·16	
At 744	744	1140	5800	0·20	
744–720	732	540	2700	0·20	
720–700	710	300	1500	0·20	
700–680	690	300	1300	0·23	1·1
680–665	672	300	1700	0·18	
At 665	665	180†	2000	0·09	

* Obtained from cooling curves of the lead baths
† Time to start of transformation
‡ Transformation commenced immediately on reaching 708° C.



(a) × 200 (b) × 1500 (c) × 200 (d) × 1500

Fig. 2—Microstructure of specimens lead-quenched to 750° C. from the austenizing temperature : (*a*) Cooled at 80° C./hr. to 600° C. and water-quenched, etched in 2% nital ; (*b*) cooled at 80° C./hr. to 600° C. and water-quenched, etched 2% aqueous picric acid ; (*c*) and (*d*) cooled at 220° C./hr. to 600° C. and water-quenched



(a) (b)

Fig. 3—X-ray pattern of specimen 1, air-cooled to 550° C. from austenizing temperature and then cooled at 5° C./hr. : (*a*) To 390° C. and water-quenched ; (*b*) to 190° C. and water-quenched

[Cameron
To face p. 314]

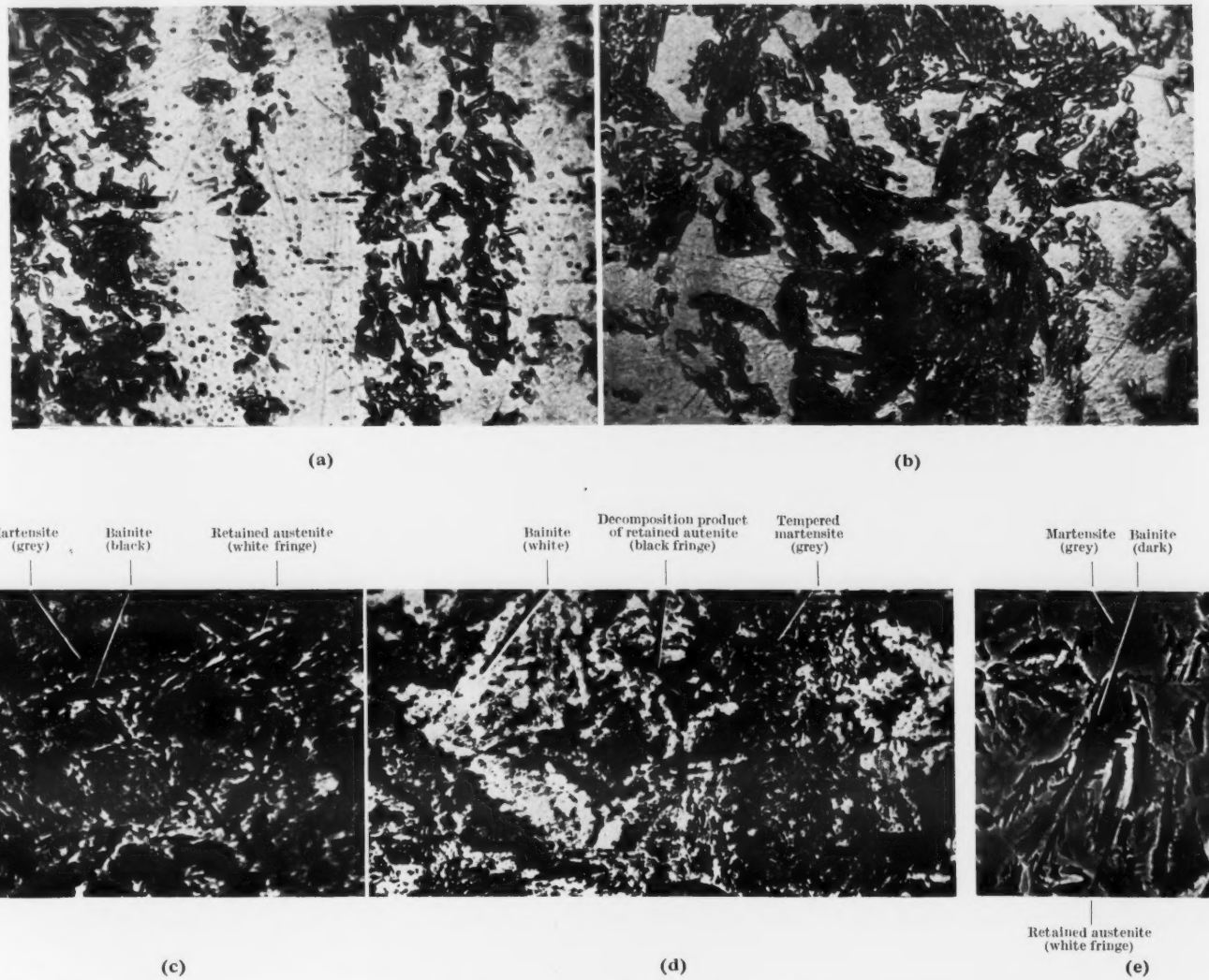


Fig. 4—Specimens air-cooled to 550° C. from austenizing temperature and then cooled at 5° C./hr. to 375° C. and water-quenched: (*a*) Etchant 2% nital × 500; (*b*) etchant 2% nital × 1500; (*c*) etchant Kalling's reagent × 1500; (*d*) tempered 15 min. at 550° C., etchant 2% nital × 1500; (*e*) electron micrograph of same specimen before tempering, etchant 2% nital (Formvar replica) × 1500

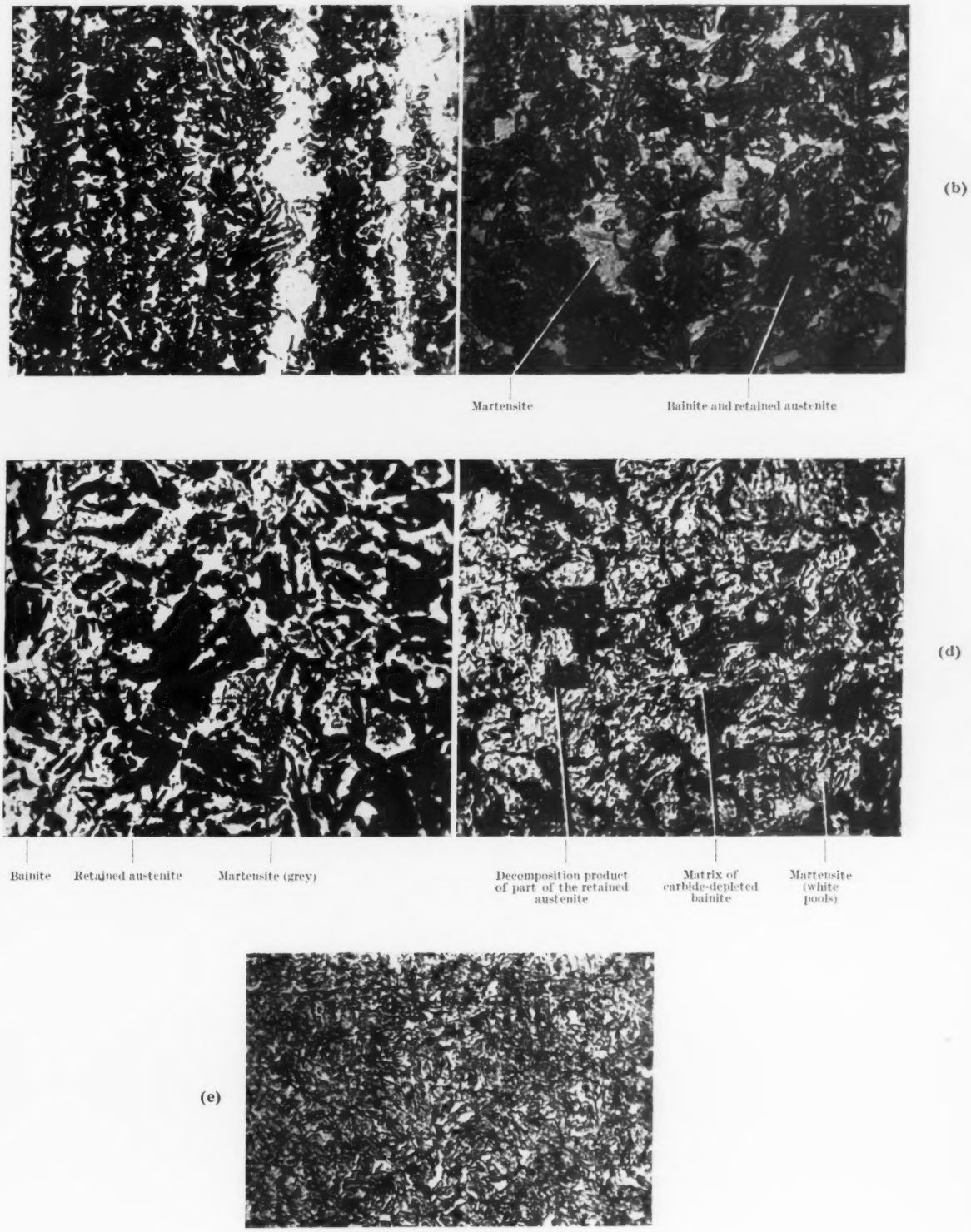


Fig. 5—Specimens air-cooled to 550° C. from austenizing temperature and then cooled at 5° C./hr. to 330° C. and water-quenched : (*a*) Etchant 2% nital × 500 ; (*b*) etchant 2% nital × 1500 ; (*c*) etchant Kalling's reagent × 1500 ; (*d*) tempered 15 min. at 550° C., water-quenched, etchant 2% nital × 1500 ; (*e*) lead-quenched for 20 hr. at 330° C., from austenizing temperature, water-quenched, etchant Kalling's reagent × 1500

[*Cameron*

XUM

Thus, the cooling rate necessary for transformation to start in the pearlite range is 225° C./hr.

Experimental Determination of Critical Cooling Rate

With the dilatometer method, no evidence of transformation was obtained in a specimen lead-quenched to 750° C., and cooled to 600° C. at less than half the calculated rate (*see* Table I). In view of previous published work, better agreement was expected, and four step-cooling treatments were therefore carried out. Each specimen was lead-quenched from the austenitizing temperature and was held for a fraction of the reaction time at a given temperature in the pearlite range. It was then cooled to a lower temperature in the pearlite range and held at this temperature until the dilatometer indicated that transformation was in progress. The specimen was then water-quenched. Details of the cooling tests, given in Table II, show that transformation began in the four tests when $\sum \frac{t_i}{t_b}$ was 1·3, 0·81, 0·90, and 1·1, respectively.

A small amount of transformation was readily detected in the isothermal and step-cooling tests because, once the specimen had reached the lead-bath temperature, the dial gauge reading was steady. During cooling experiments, however, the dial gauge was changing continually, as a result of thermal contraction of the specimen during cooling, and the start of transformation caused only a small change in the gradient of the cooling curve. Metallographic examination of a specimen cooled at 80° C./hr. from 750 to 600° C., and water-quenched, revealed a 10–15% transformation (*see* Figs. 2*a* and *b*).

In later continuous-cooling experiments metallographic examination was used to detect the beginning of transformation and the results obtained agreed reasonably well with the calculated values given in Table I. Figures 2*c* and *d* are photomicrographs of a sample cooled from 750° C. at 220° C./hr. to 600° C., and then water-quenched. The amount of transformation is about 1%.

These results indicate that the calculation of the beginning of transformation using Scheil's hypothesis is in good agreement with experimental observation and gives a practical guide to suitable cooling rates through the pearlite range.

THE BAINITE RANGE

If a cooling rate that will prevent any significant transformation in the pearlite range is chosen, then hardening is accomplished by transformation of the austenite to bainite. If the isothermal transformation diagram is any criterion, transformation to bainite should be about 90% completed after, say, 2 hr. at 300° C. (Figure 1 shows that the bainite reaction does not go beyond 90% completion within 24 hr.) Thus, if the centre of the forging were cooled and held at 300° C. for a few hours, transformation should be 90% complete and the forging should be ready for tempering. Experimental work has been carried out to determine whether predictions from the isothermal diagram are applicable to transformation in the bainite range during continuous cooling.

Table III

PROGRESS OF TRANSFORMATION IN THE BAINITE REGION

Temperature Range, ° C.	Mean Temperature, ° C.	Time to Cool Through Temperature Range, sec.	Degree of Completion of Transformation, %
410–390	400	14,400	3
390–370	380	14,400	35
370–350	360	14,400	50
350–330	340	14,400	65
330–310	320	14,400	90

Progress of Transformation

At the centre of a large forging the lower limit of the cooling rate, below 400° C., may be taken as 5° C./hr.; this cooling rate was chosen for laboratory tests.

Assuming Scheil's hypothesis, calculations for the progress of the transformation were made, using the method of Pumphrey and Jones.[5] Table III shows that transformation should be completed, as far as is possible, when the steel reaches 310° C. In the present work, no attempt was made to verify Scheil's hypothesis in the bainite range, since the induction period is relatively short for this steel and the slow cooling rate used would not permit a critical test of Scheil's incubation theory.

Figure 1 shows that transformation begins after 200 sec. at 400° C., so that after a further 14,200 sec. at 400° C. the steel should be about 3% transformed. At 380° C., the steel is 3% transformed after, say, 250 sec.; therefore, after (14,400 + 250) sec. it should be about 35% transformed. At 360° C., the steel is 35% transformed after, say, 1500 sec., so that after 15,900 sec. it is about 50% transformed. At 340° C., the steel is 50% transformed in 1200 sec. and thus in 15,600 sec. it is 65% transformed. At 320° C. the steel is 65% transformed in, say, 2000 sec., so that after 16,400 sec. it should be about 90% transformed, *i.e.*, transformation has proceeded as far as possible in this temperature range.

Several specimens, $\frac{5}{8}$ in. diameter and $\frac{1}{2}$ in. long, were given the standard austenitizing treatment followed by air-cooling to about 550° C. They were transferred to another furnace standing at 550° C., and were then cooled at 5° C./hr. During the second cooling, specimens were water-quenched from various temperatures between 500° and 190° C., and they were examined metallographically to determine the amount of transformation, and by X-ray methods to estimate the austenite present at room temperature. Hardness tests were also carried out. The results of the quenching experiments are shown in Table IV.

The sum of the metallographic estimate of bainite and the X-ray estimate of austenite at room temperature exceeds 100% (even ignoring any martensite formed on quenching). It is probable that some retained austenite in the bainite has escaped metallographic detection because it is present in an extremely finely divided state, and an allowance has been made in the isothermal diagram (Fig. 1) for a possible over-estimation of the percentage of bainite present.

Table IV

RESULTS OF QUENCHING EXPERIMENTS

Specimen No.	Temperature from which Specimen was Water-quenched, ° C.	Metallographic Estimate of Amount of Bainite, % (2% nital etch)	Hardness, DPH/30 kg.	X-Ray Estimate of Austenite at Room Temperature, %	Tempered 15 min. at 550° C. and W.Q.	
					Hardness, DPH/30 kg.	X-Ray Estimate of Amount of Retained Austenite, %
1	390	25–30	655	10	541	n.d.
2	375	40	630	10	536	n.d.
3	340	70–75	555	15	540	trace
4	330	75	527	20	540	5
5	310	85	458	25	509	15
6	270	85	456	25	509	15
7	250	85	460	25	505	15
8	190	85	458	25	504	15

n.d. = not detected

Photographs of the X-ray patterns obtained on specimens 1 and 8 (Table IV) are shown in Figs. 3*a* and *b*, respectively.

Effect of Tempering

In an attempt to facilitate the metallographic detection of the amount of retained austenite found by X-rays, specimens were held at 550° C. for 15 min. and were then water-quenched. As shown in Table IV, some of the retained austenite is removed by this tempering treatment and the hardness of specimens quenched from above 340° C. decreased, whereas those quenched from below 340° C. increased in hardness.

Although the retained austenite present (from X-ray evidence) in the specimen water-quenched from 375° C. (specimen 2, Table IV) was removed on tempering at 550° C., this tempering treatment gave an indication of the location of the retained austenite and its metallographic detection. The microstructure of specimen 2 before tempering (etchant 2% nital) appears to consist of bainite on a martensite matrix (*see* Figs. 4*a* and *b*), although some of the bainite is perhaps more like ferrite than normal bainite. On tempering at 550° C. the resemblance of the bainite to ferrite is even more marked (Fig. 4*d*) suggesting that it is almost carbide-free. This carbide-free bainite is partially enveloped by a dark fringe, presumably the decomposition product of the retained austenite. Before tempering, it was not possible to distinguish the retained austenite fringe from the matrix martensite in specimens etched in 2% nital although the two structures were revealed in the electron microscope (*see* Fig. 4*e*). Etching for 50 sec. in Kalling's reagent,[9] however, revealed darkly etching bainite enveloped by a white fringe of retained austenite on a greyish martensitic matrix (Fig. 4*c*).

For the electron micrograph (Fig. 4*e*), a Formvar replica was used with the double-layer wet-stripping technique. With this method, the relief effect produced by etching the surface of the specimen is used to distinguish between the phases present. The ' bainite,' which is the most severely attacked phase, is the darkest phase present in the micrograph, and the fringe of retained austenite, which is least attacked by the etchant, is the thinnest part of the replica and is the whitest phase shown in the electron micrograph. The photomicrograph of the specimen etched in Kalling's reagent (Fig. 4*c*) and the electron micrograph of the same specimen etched in 2% nital (Fig. 4*e*), are fairly similar.

The microstructure becomes more difficult to interpret as increasing amounts of bainite are formed.

Figures 5*a–d* are photomicrographs of specimen 4, water-quenched from 330° C. The austenite fringe is visible if the specimen is treated with Kalling's reagent before tempering. On tempering for 15 min. at 550° C., the retained austenite in specimen 4 was reduced from 20–25% to 5% and the hardness was increased from 527 to 540 DPH. The structure of the transformation product of the retained austenite on tempering, shown in Fig. 5*d*, was similar to that of specimen 2. The amount of this secondary transformation product was estimated at 15–20%.

The retained austenite of specimens quenched from below 330° C. appears to be more stable to the 15-min. treatment at 550° C. than that of those quenched from 330° C. and above, as shown in Table IV. The microstructure before and after tempering specimen 8, which was water-quenched from 190° C., was qualitatively similar to that illustrated in Fig. 4. On tempering, however, only about 2% of retained austenite decomposed to the darkly etching product (etchant 2% nital) similar to that observed in specimens 2 and 4. The decomposition product of the other 8% of retained austenite (which was shown by X-ray examination to transform) may be martensite formed on quenching from the tempering temperature (*see* p. 318).

Discussion of Results

The amounts of bainite, quoted in Table IV and estimated from the 2% nital etch, are probably overestimated by about 10% (especially in the specimens water-quenched from 340° C. and below) relative to the amounts of bainite observed using Kalling's reagent. A comparison of the calculated (Table III) and observed (Table IV) progress of transformation to bainite is given in Fig. 6 and shows that the method of Pumphrey and Jones gives a general indication of the progress of transformation down to about 340° C.,

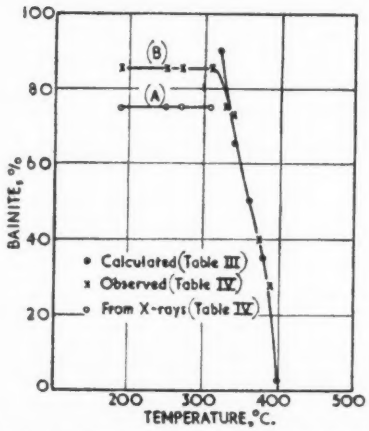


Fig. 6—Upper limit of percentage of bainite

but gives no indication of the ' freezing ' of the transformation process which occurs at about 310° C. with this steel. Curve *A* in Fig. 6 shows the upper limit of the percentage of bainite, deduced from the X-ray data in Table IV, and is probably more representative of the upper limit than is curve *B*.

The banded structure of the steel used in these experiments (*see* Figs. 4*a* and 5*a*) cannot account for the occurrence of retained austenite, because similar results were obtained with samples homogenized by pretreatment at 1275° C.

In the tests detailed in Table IV, the rate of cooling from 940° to 550° C. was extremely fast compared with the rate occurring in practice. A repeat experiment, however, cooling at a rate of 350° C./hr. from 940° C. to 550° C. before transferring to the second furnace at 550° C., gave almost identical results, as shown in Table V.

BAINITIC RETAINED AUSTENITE

Carbon Content

With the 0·4% C, 3% Cr steel no retained austenite was detected by X-rays with specimens water-quenched from 940° C. The M_f point (*i.e.*, the temperature of completion of the martensite reaction) of this steel should be appreciably above room temperature, possibly about 100° C. The M_s point was determined dilatometrically, and, as indicated in Fig. 1, was found to be about 285° C. There appears,

Table V

QUENCHING EXPERIMENTS WITH A COOLING RATE OF 350° C./HR. FROM 940–550° C.

Specimen No.	Temp. from which Specimen was Water-quenched, °C.	X-Ray Estimate of Austenite at Room Temperature, %	Hardness, DPH/30 kg.
10	620	nil	690
11	340	10	541
12	325	20	492
13	320	20	514
14	305	25	465
15	205	25	462
16	190*	25	457

* Air-cooled

Table VI

CARBON CONTENT OF RETAINED AUSTENITE

Specimen No.	Austenite Lattice Spacing, Å.	Carbon Content of Austenite, %
3	3·60	1·0
5	3·61	1·2
8	3·61	1·2

therefore, to be an essential difference between the parent austenite in the steel and the retained austenite, referred to in Tables IV and V, which may be termed ' bainite retained austenite,' some characteristics of which have been investigated.

The carbon content of the retained austenite in specimens 3, 5, and 8 (*see* Table IV) was deduced from lattice parameter measurements,[8] and the results are given in Table VI.

Twenty-five per cent. of retained austenite containing 1·2% of carbon accounts for three-quarters of the total carbon (0·41%) in the steel. This finding is consistent with the earlier deduction that the bainite may be almost carbide-free. The remaining quarter of the 0·41% of carbon in the steel is probably in the martensite, which is formed on quenching. That the carbon content of a proportion of the parent austenite is increased to over 1% by slow cooling through the bainite range, is consistent qualitatively with the work of Klier and Lyman[10] and Hultgren[11] on the mechanism of bainite formation.

Isothermal Tests

A few isothermal tests were conducted at selected temperatures, above, within, and below the bainite range, to determine whether retained austenite was obtained isothermally. Specimens, given the standard austenitizing treatment, were quenched into a solder bath at one of the selected temperatures and were held at this temperature for 20 hr. and were then water-quenched. In addition to the 20-hr. tests, specimens were held for 10 min. and for 2 hr. at 390° C. and at 330° C. The results of X-ray, metallographic, and hardness examination of these specimens are shown in Table VII, from which it appears that X-ray estimates of retained austenite in the specimens transformed isothermally within the bainite range are lower than those for specimens cooled at 5° C./hr. through the bainite range.

Specimens transformed isothermally have a much finer microstructure than those transformed during cooling at 5° C./hr. (*cf.* Figs. 5*e* and *c*).

Faster Rate of Cooling

Below 500° C. bainitic retained austenite has been observed at a cooling rate of 5° C./hr., and a second series of tests was carried out to determine whether similar results would be obtained at a faster cooling rate. The $\frac{5}{8}$-in. dia. specimens were held at 940° C. for 30 min., cooled at a rate of 400° C./hr. to 550° C., then at 95° C./hr. down to 205° C. Specimens were water-quenched from various temperatures and were examined as before. The results are shown in Table VIII. The amounts of retained austenite are less than those occurring at the slower cooling rate

Table VII

ISOTHERMAL TRANSFORMATION WITHIN THE BAINITE RANGE

Specimen No.	Temp. from which Specimen was Water-quenched, °C.	Time Held at this Temp. Before Water-quenched	X-Ray Estimate of Austenite at Room Temperature, %	Metallographic Estimate of Amount of Bainite, %	Hardness, DPH/30 kg.
17	437	20 hr.	n.d.	nil	725
18	390	10 min.	n.d.	2	685
19		2 hr.	< 5	15	658
20		20 hr.	< 5	30	632
21	380	20 hr.	< 5	35	636
22	360	20 hr.	10–15	50	543
23	350	20 hr.	10–15	60–65	512
24	340	20 hr.	10–15	65	503
25	330	10 min.	< 5	20	603
26		2 hr.	10–15	85	511
27		20 hr.	10–15	85	492
28	320	20 hr.	5–10	90	516
29	300	20 hr.	5–10	90	557
30	280	20 hr.	< 5	...	569

n.d. = not detected (the smallest amount of retained austenite which could be detected by the X-ray method was about 3%)

through the bainite range, but the transformation again 'freezes' at about 310° C. For continuous cooling through the bainite range the slower cooling rate, therefore, favours the retention of austenite.

Stability on Tempering

Incomplete transformation of austenite to bainite is apparently inevitable with the steel used in the present investigation at the cooling rates employed. The extent to which untransformed austenite may be removed in the tempering phase of the heat-treatment cycle was therefore determined.

When specimen 13 (*see* Table V) was water-quenched from 320° C., three similar specimens were simultaneously transferred to a furnace at 350° C., and were heated at a rate of 50° C./hr. At 500° C., 600° C., and 715° C., specimens were water-quenched; the results of hardness and X-ray tests on these specimens are shown in Table IX.

When specimen 15 (*see* Table V) was water-quenched from 205° C., a similar specimen (43) was transferred to a furnace at 240° C. and heated at 100° C./hr. to 500° C., was held at this temperature for 2½ hr., and was then furnace-cooled to room temperature. X-ray and hardness tests on specimen 43 gave the austenite as 15% and hardness as 505 DPH compared with 25% austenite and 462 DPH for specimen 15 (Table V). The hardness increase on tempering is thought to be associated with 'conditioning' of the austenite at the tempering temperature.

A dilatometer specimen, 0·35 in. dia. and 4 in. long, was treated as for specimen 5, namely 30 min.

Table VIII

BAINITIC RETAINED AUSTENITE : COOLING RATE 95° C./HR.

Specimen No.	Temperature from which Specimen was Water-quenched, °C.	X-Ray Estimate of Austenite at Room Temperature, %	Hardness, DPH/30 kg.
31	620	n.d.	775
32	420	n.d.	720
33	375	< 5	600
34	345	5–10	569
35	320	10–15	496
36	295	15–20	476
37	270	15–20	469
38	250	15–20	469
39	205	15–20	468

n.d. = not detected

Table IX

EFFECT OF TEMPERING

Specimen No.	Treatment After Reaching 320° C.	X-Ray Estimate of Austenite at Room Temperature, %	Hardness DPH/30 kg.
13	320° C., W.Q.	20	514
40	50° C./hr. to 500° C.	15	529
41	50° C./hr. to 600° C.	5	586
42	50° C./hr. to 715° C.	n.d.	313

n.d. = not detected

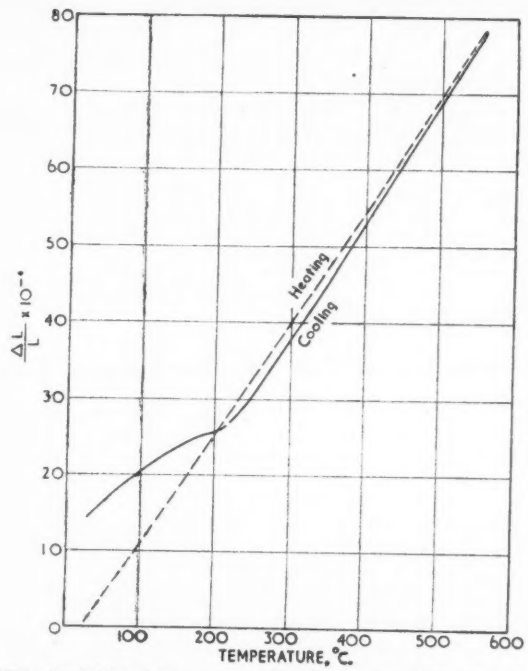


Fig. 7—Dilatation curves showing ' conditioning ' of retained austenite

at 940° C., air-cooled to 550° C., then cooled at 5° C. /hr. to 310° C. and water-quenched. The specimen was then set up in a dial gauge dilatometer, was heated to 555° C., held at that temperature for 2½ hr., and was then air-cooled. The heating and cooling curves obtained are shown in Fig. 7. Before the test, the specimen contained 25% retained austenite (by X-ray) and had a hardness of 454 DPH. After test, the retained austenite content was 5% and the hardness was 538 DPH.

The cooling curve indicates the decomposition of retained austenite below 210° C. The transformation of the retained austenite may be responsible for the increase in hardness observed on cooling this specimen.

The ' conditioning ' of the retained austenite is rather complex and work on it is still in progress.

Stability on Refrigeration

A few tests were carried out to determine the stability of bainitic retained austenite on refrigeration at −78° C.

When specimens 12, 14, and 16 were removed from the furnace at 325° C., 305° C., and 190° C. respectively, a second specimen was simultaneously water-quenched and, immediately on attaining water temperature, this second specimen was given a cold-treatment of 1½ hr. at −78° C. The hardness of these specimens together with X-ray estimates of the quantities of austenite at room temperature before and after refrigeration are given in Table X. The results indicate that the stability of the retained austenite on refrigeration at −78° C. increases as the quenching temperature is decreased. Thus, although the transformation is ' frozen ' at about 310° C., slow cooling to lower temperatures increases the stability of the retained austenite.

CONCLUSIONS AND DISCUSSION OF RESULTS

Results show that for the steel under investigation, a reasonable estimate may be made of the critical cooling rate through the pearlite range by the use of Scheil's hypothesis. The method of Pumphrey and Jones, for following the course of transformation, is not, however, satisfactory for studying the complexity of the bainite transformation in 3% Cr–Mo steel.

Klier and Lyman[10] obtained retained austenite in low-carbon steels by isothermal transformation in the bainite range. In the present investigation, 10–15% of retained austenite was observed after isothermal transformation between 360° and 330° C., but twice this amount occurred by cooling through the bainite range at 5° C./hr. No satisfactory theory to explain the mechanism of the bainite transformation has yet been developed and it is difficult to explain the difference between the percentage of retained austenite formed isothermally and that formed by slow cooling.

Zener[12] suggests that the bainite reaction commences with the formation of ferrite by a diffusionless transformation of the martensitic type. As with the start of the martensite reaction, the temperature at which bainite formation commences depends on the carbon content of the austenite—the critical temperature decreases as the carbon content increases. The ferrite grain loses carbon by diffusion into the surrounding austenite, resulting in an increase in the carbon content of the austenite, which lowers the critical temperature of formation of bainite. Thus, if the temperature remains constant, the reaction ceases, and further transformation can only be obtained if the temperature is lowered.

This picture of the bainite transformation appears to be directly applicable to the 3% Cr–Mo steel used

Table X
EFFECT OF REFRIGERATION

Specimen No.	Treatment After Water-quenching or Air-cooling	Before Refrigeration		After Refrigeration	
		Austenite, %	Hardness, DPH/30 kg.	Austenite, %	Hardness, DPH/30 kg.
12 44	None 1½ hr. at 78° C.	20	492	5	548
14 45	None 1½ hr. at 78° C.	25	465	10	516
16 46	None 1½ hr. at 78° C.	25	457	25	456

in the present investigation. The amount of retained austenite in this steel after isothermal transformation reaches a maximum of 10–15% at 360–330° C. Less retained austenite is obtained at higher or lower temperatures. At higher temperatures, the amount of ferrite formed in the diffusionless transformation is small and, although the rate of diffusion of carbon is high, the enrichment of the austenite by the carbon rejected by this small amount of ferrite is insufficient to render it stable at room temperature. At lower temperatures, much more ferrite (90% at 320° C.) is formed by diffusionless transformation, and thus the maximum retained austenite is 10%.

During slow cooling through the bainite region, transformation commences at about 400° C., and the amount of ferrite formed will be small. The rate of diffusion of carbon will be relatively high; thus, provided that the cooling rate is slow, the carbon will become fairly uniformly distributed throughout the remaining austenite. As the temperature falls, more ferrite will form and the carbon content of the austenite will be further increased. In general, the enhancement of the carbon content of the austenite may be insufficient to depress the M_f point below room temperature, but with the steel under consideration, the carbon content of the austenite may rise to 1·2%, resulting in the depression of the M_f point below room temperature.

Although the observations made in the present work agree with Zener's picture of the bainite transformation, it has been assumed that the bainite transformation, like the martensite transformation, is only temperature-dependent and not time-dependent. The formation of ferrite is not, however, a spontaneous diffusionless transformation—there is an incubation period and the reaction takes time to complete. This suggests a process of incubation and growth as postulated by Hultgren.[11] A more satisfactory explanation of the results obtained with the 3% Cr–Mo steel cannot be given until the mechanism of the bainite transformation is more fully understood.

Acknowledgments

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Historical Note No. 28

Early Use of Cast Iron for Furnace Tops

By Dr. H. R. Schubert

The early charcoal blast-furnace was open at the top, the gas being allowed to burn away. Early writers were greatly impressed by the flames rising from the furnaces. Gerard Boate, Doctor of Physic to the State of Ireland, who collected the material for his history of contemporary Ireland in 1645, wrote about the furnaces erected on the English plantations in Ireland as follows: "*the mouth or top . . . is not covered, but open all over; so that the flame, when the furnace is kindled, rising through the same without any hindrance, may be seen a great way off in the night.*"[1] Thomas Baskerville, who travelled from Ross to Gloucester in 1682 and saw a furnace near Longhope, described it by saying "*the flame mounts fiercely a good height above the furnace.*"[2]

The ironmasters, however, were less impressed by this spectacular sight as they were too much concerned about the effect such flames had upon the buildings. The strong heat and pieces of iron ore carried up by the flames were liable to damage the stonework of the furnace mouth, which accordingly required frequent repairs. At Panningridge, in Sussex, for example, it had to be repaired twice in the one year of 1551.[3] Some time later a new device was discovered. To protect the stonework cast-iron plates were laid round the mouth of the furnace. Documentary evidence shows that this had been done in Yorkshire before the end of the sixteenth century. An item in the accounts of the furnace at Rievaulx of 1591 is as follows: "*Casting four plaites to the furnace toppe.*"[4] This is the earliest evidence of the application of such a device. More particulars are also supplied by a description of the furnace at Leightonbeck, in Lancashire, erected in 1715. It is stated that "*The Top of the Furnace is covered with a large thick Iron Plate, in the Middle of which is a Hole about ¾ of a Yard square, where they throw in the Fuel and Ore.*"[5]

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Dr. Schubert is Historical Investigator to The Iron and Steel Institute.

[1] G. Boate, Ireland's Naturall History, p. 131, London, 1652.

[2] Historical Manuscript Commission, The Manuscripts of His Grace the Duke of Portland, preserved at Welbeck Abbey, vol. II, p. 293, London, 1893.

[3] Documents of Lord De L'Isle and Dudley, Penshurst Place, No. 382.

[4] Documents of His Grace the Duke of Rutland, preserved at Belvoir Castle, No. 529.

[5] The Victoria History of the County of Lancaster, vol. II, p. 361, London, 1908.

Tests on Heat-Resisting Cast Irons

By M. M. Hallett, M.Sc., F.I.M.

SYNOPSIS

The resistance to oxidation of a wide range of alloy cast irons has been determined in air and in a sulphurous atmosphere in the temperature range 750–1050° C. A clear comparison may be drawn between the various irons, and the effects of the alloying elements nickel, silicon, and chromium are illustrated. The growth of the scaled specimens was measured and their microstructures were examined. The mechanism of internal oxidation in the different materials was observed.

Tests on the relative susceptibility to cracking of the same series of irons revealed characteristic differences. In line with the laboratory work, the same irons were cast into furnace parts and were subjected to normal furnace operations. The results of these service tests could be correlated closely with the laboratory test results.

Small alloy additions improve scaling at relatively low temperatures, and silicon is particularly good in reducing oxidation at temperatures up to about 900° C. Above this its efficiency drops appreciably. The high-chromium irons are particularly resistant to the highest temperature studied, and are less prone to cracking than would be expected, provided that the sections are relatively thin so as to avoid thermal stresses.

During the past 20 years many heat-resisting cast irons have been developed, including a wide range of alloy elements and contents, and although test results on heat resistance were frequently quoted, the different investigators did not employ the same experimental methods, so that it is extremely difficult to compare results quantitatively. The purpose of the present investigation was to compare, on the same basis, all the usual heat-resisting irons so as to provide accurate relative data which would enable a more reliable choice to be made of the most suitable material for any given set of conditions. The work included studies of resistance to scaling at various temperatures in air and in sulphurous atmospheres, thus simulating the conditions in electric furnaces and in oil- or coal-fired furnaces. Heat-resisting cast iron is more prone to failure by cracking than is heat-resisting steel, and it was felt desirable to determine the relative susceptibility to cracking of the alloy irons. Information was also gained on growth, and observations were made on changes in microstructure. Service tests carried out under controlled industrial conditions on some of the same cast irons made from the same ladles of metal as the laboratory test specimens made possible an appraisal of the irons from both laboratory tests and service performance.

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EXPERIMENTAL MATERIALS

The irons used (listed in Table I) range from a low-Si hematite iron (*S.S.M.P.*), through a low Ni–Cr iron (*A.P.*), a high-Si iron (Silal), to high-Ni irons and high-Cr irons. The high-alloy Ni-Resist and Nicrosilal irons were studied at two Cr levels, about 2½ and 5%, and the high-Cr ferritic irons at 16 and 33%. The only novel iron studied had 10% of Ni added to the 33% Cr iron base. It was hoped that this addition would increase the toughness of the iron.

TESTS IN AIR

Scaling Tests

These tests were carried out in a laboratory electric muffle furnace with holes in the door and in the back of the furnace for circulation of air by natural draught. The specimens, machined cylindrical pieces ½ in. in dia. and 1 in. long, were each placed upright on asbestos paper in the centre of a small roasting dish and were loaded into the cold furnace, which was then raised gradually to the desired temperature. After exposure for the determined time, each dish and specimen was removed from the hot furnace, placed

Table I

ANALYSIS OF EXPERIMENTAL MATERIALS

Material	T.C., %	Si, %	Mn, %	P, %	Ni, %	Cr, %	Cu, %
S.S.M.P. ...	2·98	1·14	1·07	0·18	...	...	...
A.P.	3·45	1·64	1·03	0·15	1·18	0·92	...
Silal	1·89	5·70	0·96	0·16	Nil	0·05	...
Ni-Resist ...	2·74	1·93	0·89	0·04	14·62	2·11	7·16
Ni-Resist (5 Cr)	2·85	1·85	0·83	...	14·38	4·84	7·36
Nicrosilal ...	1·78	4·63	0·91	0·10	22·46	2·52	...
Nicrosilal (5 Cr)	2·10	4·90	0·89	0·05	22·79	4·63	...
Enduron ...	2·14	1·54	1·56	...	0·20	16·60	...
33 Cr	1·28	1·17	0·75	...	0·24	33·03	...
30 Cr, 10 Ni ...	1·12	1·78	0·57	...	9·36	29·62	...

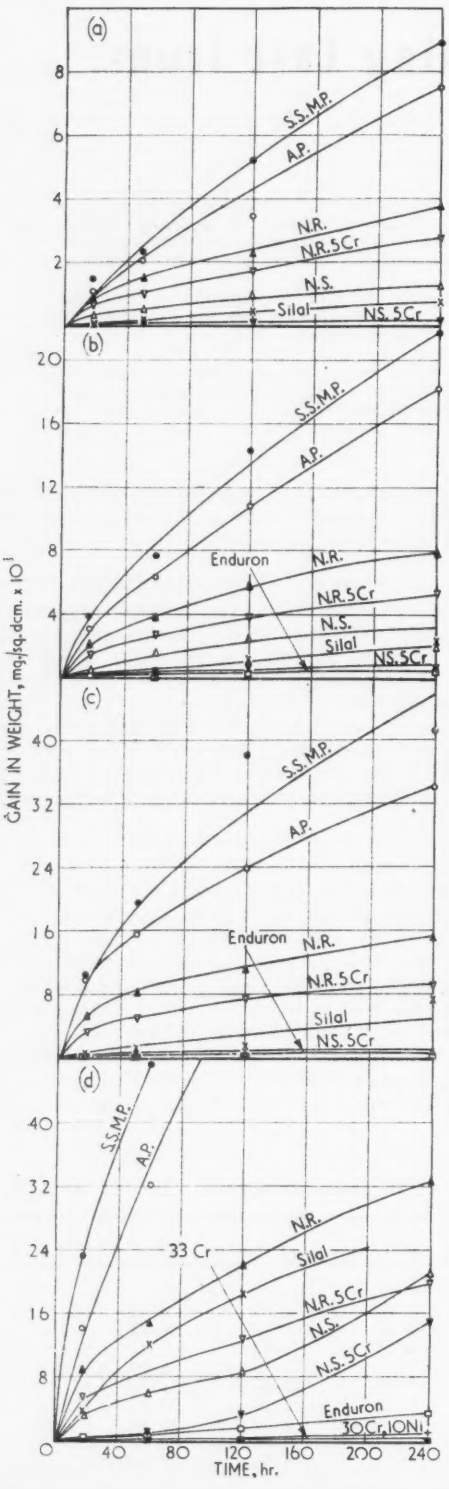

Fig. 1—Scaling tests in air : (a) 750° C., (b) 850° C., (c) 950° C., (d) 1050° C.

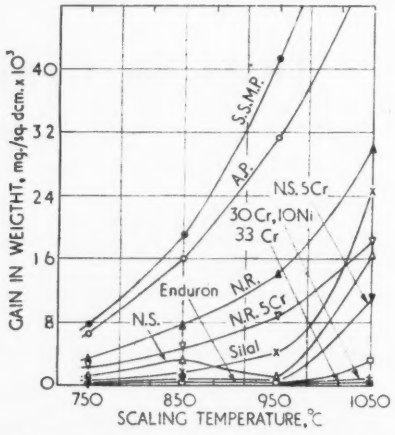

Fig. 2—Comparative scaling after 200 hr. in air

on a glazed tile, and a small sheet-iron cone was dropped over the top of the dish and specimen to act as a cover for retaining any scale thrown off the specimen during cooling. The roasting dish and the glazed tile were subsequently brushed free from scale and the total weight of the specimen and scale was determined.

At first it was not known whether gain in weight, as given by the method described, or loss in weight of the specimen after hammering to remove the scale, would be the more reliable. All specimens were therefore weighed by both methods, but the gain-in-weight figures were much more reliable and consistent, and only they are quoted.

It was desired to determine the growth characteristics of the irons without the complication due to the thickness of the scale. Preliminary experiments indicated that chromium-plating the ends of the specimens protected them over quite a wide temperature range. Accordingly, all the specimens were chromium-plated on each end, thus providing a scale-free surface for micrometer measurements. As it was impossible to chromium-plate the Silal specimens, they had to be measured with the scale layer, but in the other cases a satisfactory plate was applied and the results will be discussed at the appropriate point.

Preliminary checks on temperature distribution showed that at 1000° C. the variation over the floor of the furnace was within $\pm$ 5° C. In addition, the specimens were placed in different positions for different runs, a separate specimen being used for each time at each temperature. Three samples of Ni-Resist, oxidized for 48 hr. at 900° C., showed a variation in gain of weight of only 2·39 to 2·50%.

Tests were carried out at 750°, 850°, 950°, and 1050° C., and at each temperature specimens were exposed for 18, 48, 120, and 240 hr. Figure 1 shows the gain in weight with time on each material at each temperature, and Fig. 2 summarizes these tests by indicating the increase in weight at an arbitrary time of 200 hr., with temperature. This value seemed to be at a point on the curves where behaviour was fairly steady, and at which the most reliable results could be expected.

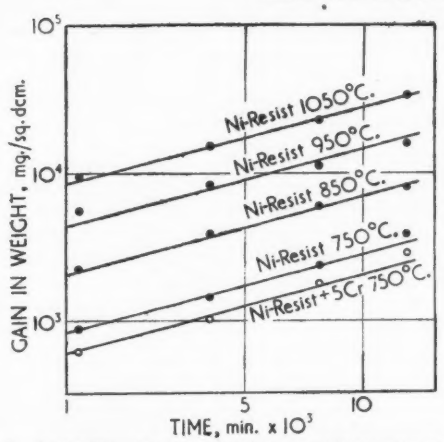

Fig. 3—Logarithmic plot of gain in weight against time

Taking the unalloyed low-Si hematite iron, *S.S.M.P.*, as a standard (though this has in itself a better resistance to heat than a general engineering grey iron), the addition of 1% each of Ni and Cr reduced the rate of scaling by about 15% over the full temperature range. In these low-alloy materials the apparent rate of attack at 1050° C. was limited by complete conversion of the specimen into oxide. The 6% Si iron Silal, had an excellent performance up to about 900° C., and is probably the most economical iron for this temperature range.

Of the austenitic irons, Ni-Resist was inferior to Silal, and even the high-Si Nicrosilal austenitic iron was inferior to Silal at temperatures up to 850° C. A high Cr content in the austenitic irons improved the scaling resistance by amounts ranging from one-third to three-quarters. The higher Cr contents, however, introduced considerable practical difficulties and the irons were troublesome to machine owing to the large amounts of chromium carbide.

A curious feature shown by Nicrosilal, with both normal and high Cr, is the dip in the curve at 950° C. (Fig. 2). It is difficult to believe that this result could be reproduced, but it was definite on 14 out of 16 specimens studied at 850° and 950° C. There was no possibility of mixing, and microscopical examination did not throw any light on the question.

The high-Cr ferritic irons gave the best performance of all, and the addition of 33% of Cr would appear to enable the iron to resist scaling in air at 1050° C. almost indefinitely. The addition of 10% of Ni to this material did not further improve the resistance to scaling.

Although the number of determinations on any one material was relatively small, it seemed worth while to see if they were in accordance with the predictions of theory. It has long been recognized, since its demonstration by Pilling and Bedworth,* that the rate of growth of a uniform scale is proportional to the square-root of time, and Heindlhofer and Larsen† demonstrated that pure iron heated in air at temperatures between 700° and 1100° C. obeyed this law.

When the results obtained on the cast irons in air were plotted on logarithmic scales, at all temperatures the values for the hematite iron (*S.S.M.P.*) and for the low Ni–Cr iron (*A.P.*) fell roughly on straight lines, though generally at a somewhat steeper slope than that required by the square law. With the other materials the points were generally too scattered to be of much value, except Ni-Resist of high and low Cr contents.

In Fig. 3, on a double logarithmic scale, are plotted all the points for Ni-Resist at the four temperatures. At each temperature the points for the higher-Cr Ni-Resist gave a line a little below that of the low-Cr Ni-Resist, but, to avoid confusion, the only results plotted for the higher-Cr Ni-Resist are those at 750° C. All the straight lines have been drawn at the slope required by the square law, to indicate the slight departure of the experimental results from the theoretical rate.

Heindlhofer and Larsen (*loc. cit.*) also showed that pure iron gave a straight line when the logarithm of the gain in weight was plotted against the reciprocal of the absolute temperature. The data plotted in normal co-ordinates in Fig. 2 were therefore replotted on a logarithmic scale against the reciprocal of the absolute temperature, Fig. 4. Again, the Ni-Resist of both Cr contents gave reasonably consistent results, though with some variation at 1050° C., whilst the two lower-alloy irons were also satisfactory at 950° C. and below. Other materials, with the possible exception of Enduron, did not give reproducible values.

Both methods of plotting indicate consistent behaviour only with the two Ni-Resist compositions, though the two low-alloy irons were not altogether irregular. This indicates a fairly steady and uniform growth of the oxide scale on the Ni-Resist irons, and a steady growth at a somewhat higher rate on the low-alloy materials. This higher rate is presumably connected with fissuring of the scale, permitting more

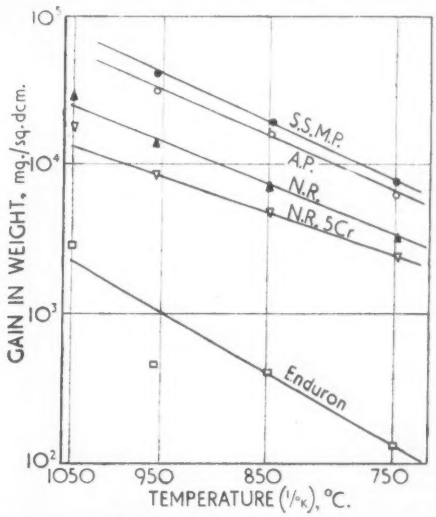

Fig. 4—Logarithm of the increase in weight after 200-hr. oxidation in air plotted against the reciprocal of the absolute temperature

* N. B. Pilling and R. E. Bedworth, *J. Inst. Metals*, 1923, vol. 29, p. 529.

† K. Heindlhofer and B. M. Larsen, *Trans. Amer. Soc. Steel Treat.*, 1933, vol. 21, p. 865.

rapid oxidation. The rate of scaling of the higher-alloy irons over most of the temperature range seems to be too low for the experimental technique to give sufficiently regular results.

Growth Tests

As already mentioned, the specimens were chromium-plated on the ends to furnish a scale-free surface for length measurements before and after exposure to temperature. The results are set out in Table II. In spite of the chromium-plating, protection was not really effective at the top temperature. The results show considerable variation, but they give a general indication of the order of linear growth to be expected. As remarked earlier, it was not possible to chromium-plate the Silal specimens, and the high figures for this iron are due to the values necessarily including the thickness of the scale. The true growth would be expected to be appreciably lower.

Microstructure

All the specimens heated for 120 hr. were sectioned and examined microscopically. As the scale layers were removed by hammering for the purpose of the scaling tests, only the changes in the cast iron below the scale layers could be examined.

In the unalloyed or low-alloy irons several zones of oxidation were distinguished. Near the surface the

Table II

RESULTS OF GROWTH TESTS

Results on Silal include thickness of scale layer

Material	Linear Growth, %			
	18 Hr.	50 Hr.	120 Hr.	240 Hr.
Temperature 750° C.				
S.S.M.P.	0·1	0·2	0·45	0·4
A.P.	Nil	0·15	0·3	0·3
Silal	0·2	0·5	0·4	0·6
Ni-Resist	0·1	0·1	0·05	0·4
Ni-Resist (5 Cr)	Nil	Nil	Nil	0·2
Nicrosilal	Nil	Nil	Nil	Nil
Nicrosilal (5 Cr)	Nil	Nil	Nil	0·1
Enduron	Nil	Nil	0·05	0·2
33 Cr	Nil	Nil	Nil	0·1
30 Cr, 10 Ni	Nil	Nil	Nil	Nil
Temperature 850° C.				
S.S.M.P.	0·1	0·3	0·4	1·25
A.P.	0·1	0·05	0·15	0·7
Silal	0·8	1·0	1·9	3·2
Ni-Resist	0·15	0·15	0·3	0·3
Ni-Resist (5 Cr)	0·1	0·25	0·25	0·4
Nicrosilal	0·05	Nil	0·05	0·05
Nicrosilal (5 Cr)	Nil	0·05	0·25	Nil
Enduron	Nil	Nil	0·05	0·2
33 Cr	Nil	0·05	Nil	Nil
30 Cr, 10 Ni	Nil	Nil	Nil	Nil
Temperature 950° C.				
S.S.M.P.	0·3	0·3	1·2	0·95
A.P.	0·7	0·6	1·2	1·4
Silal	1·25	1·0	1·9	3·8
Ni-Resist	0·6	Nil	Nil	0·75
Ni-Resist (5 Cr)	0·3	0·1	Nil	Nil
Nicrosilal	0·2	0·1	Nil	Nil
Nicrosilal (5 Cr)	0·2	Nil	Nil	Nil
Enduron	1·15	0·4	0·2	Nil
33 Cr	0·9	0·2	Nil	Nil
30 Cr, 10 Ni	0·45	0·1	0·1	Nil
Temperature 1050° C.				
S.S.M.P.	0·35	Nil	Nil	...
A.P.	0·4	9·4	2·3	4·3
Silal	0·7	1·0	2·0	2·4
Ni-Resist	0·1	0·3	4·5	1·7
Ni-Resist (5 Cr)	0·1	...	Nil	0·7
Nicrosilal	Nil	0·1	Nil	1·4
Nicrosilal (5 Cr)	Nil	Nil	Nil	1·6
Enduron	Nil	Nil	0·1	0·5
33 Cr	Nil	0·2	0·3	0·8
30 Cr, 10 Ni	0·8	Nil	Nil	0·15

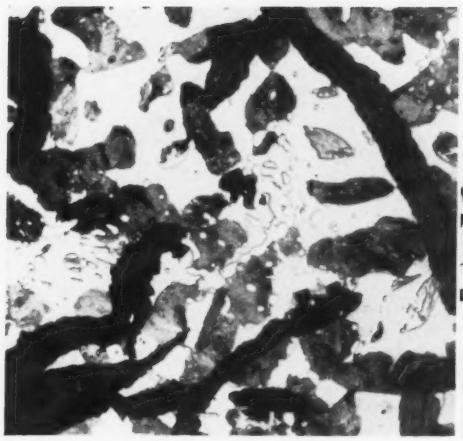

Fig. 5—Structure at centre of S.S.M.P. after 120 hr. at 750° C. Etched × 600

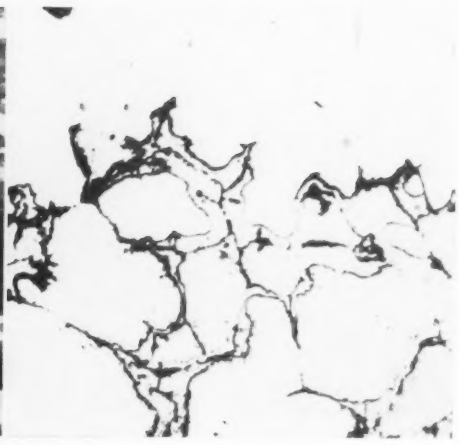

Fig. 6—Oxidation along graphite flakes in S.S.M.P. at 850° C. × 600

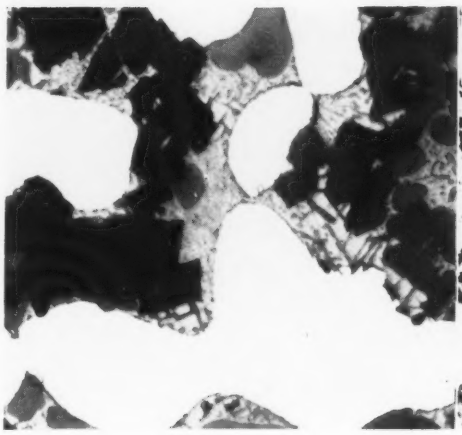

Fig. 7—Oxide phases in S.S.M.P. at 1050° C. × 600

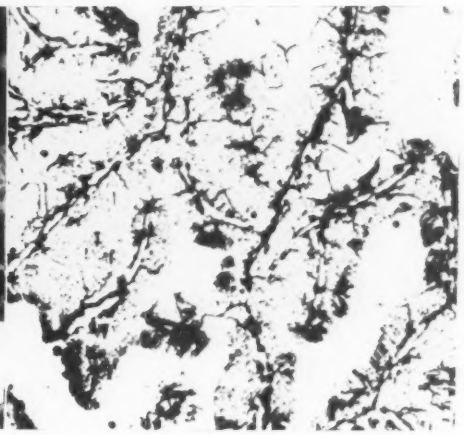

Fig. 8—Oxidation around graphite in A.P. at 850° C. × 600

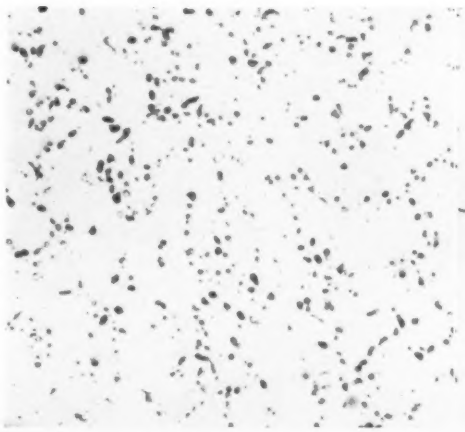

Fig. 9—Band of graphite elimination in Silal at 950° C. × 100

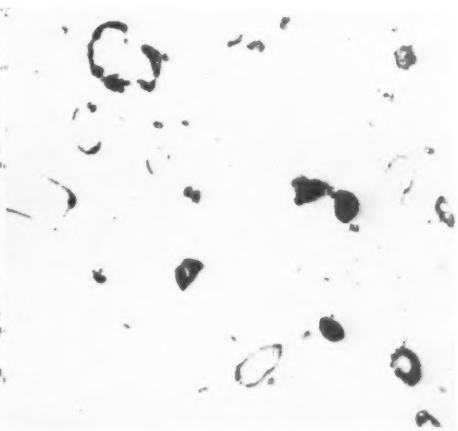

Fig. 10—Same zone as in Fig. 9 × 600

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Fig. 11—General view of oxidation of Ni-Resist at 750° C. Original surface on left × 200

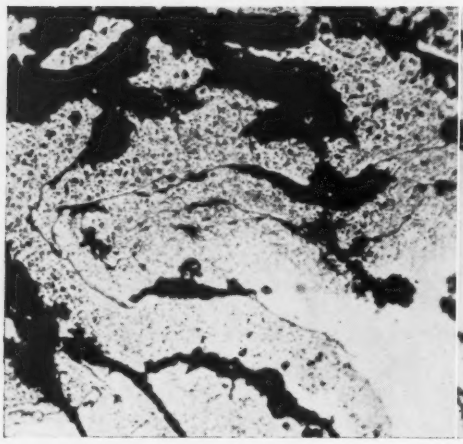

Fig. 12—Heavily oxidized region of Fig. 11 × 600

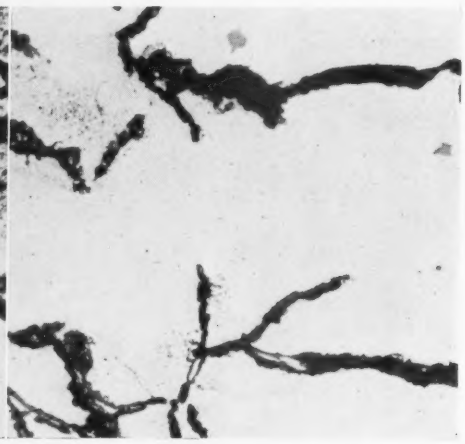

Fig. 13—Less oxidized region of Fig. 11 × 600

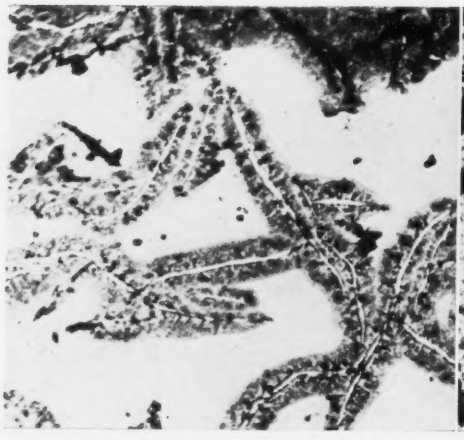

Fig. 14—Oxidation of Ni-Resist at 850° C. × 300

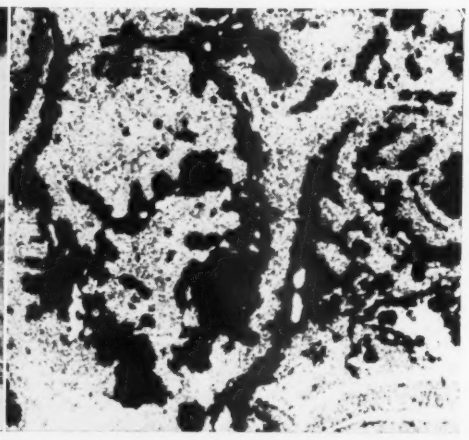

Fig. 15—Heavily oxidized region of Fig. 14 × 600

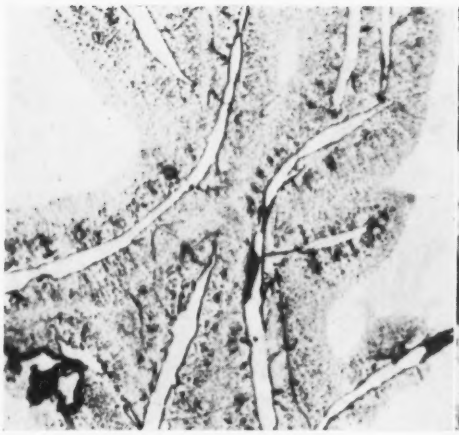

Fig. 16—Oxidation of graphite flakes in Ni-Resist at 850° C. × 1000

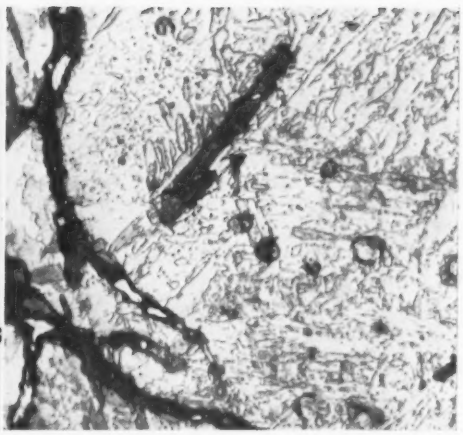

Fig. 17—Martensite in Ni-Resist after oxidation at 1050° C. × 600

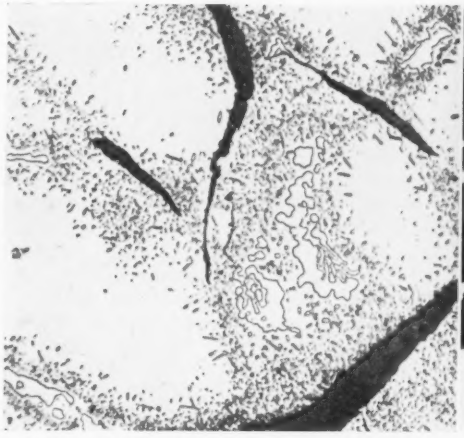

Fig. 18—Carbide precipitation in Nicrosilal at 750° C. Etched × 600

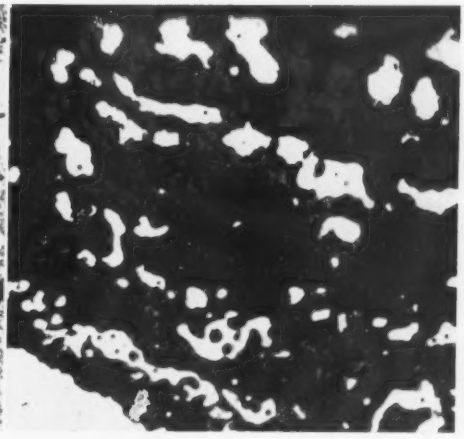

Fig. 19—Scale structure on Nicrosilal at 1050° C. × 600

Fig. 20—Surface oxidation of Enduron at 1050° C. Etched × 300

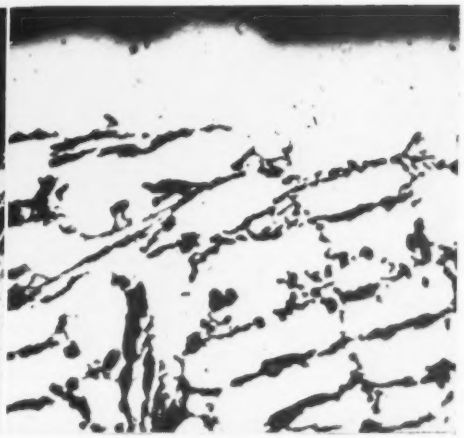

Fig. 21—Surface oxidation of 33% Cr iron at 1050° C. Etched × 300

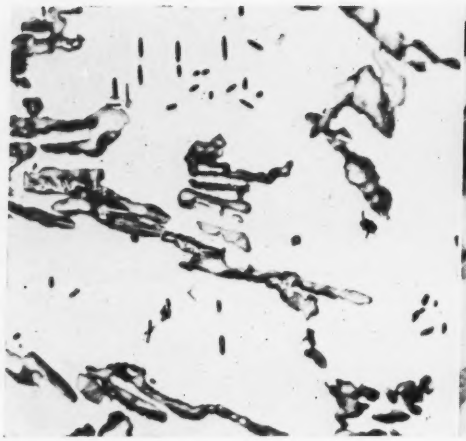

Fig. 22—Carbides and sigma phase in 33% Cr iron at 950° C. Etched × 600

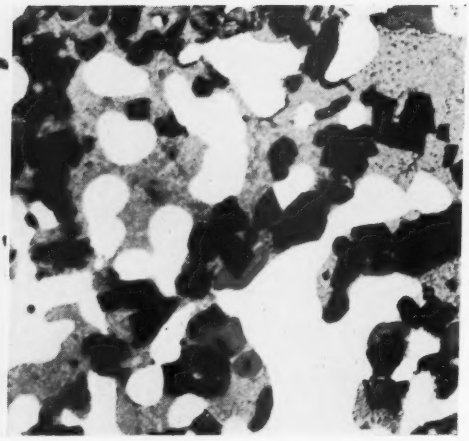

Fig. 23—Oxide phases in S.S.M.P. scaled in sulphurous atmosphere at 975° C. × 600

Fig. 24—Design of base plate and cover used for service tests

flakes of graphite were completely replaced by oxide, and much precipitation of oxide occurred in the surrounding metallic matrix. Below this zone preferential oxidation along graphite flakes was clearly revealed by precipitation of oxides in the surrounding matrix. In the interior of the specimen, depending on the temperature, the effects might be due only to annealing. For example, at 750° C. the unalloyed iron had been heated at a temperature at which it was partly austenitic and partly ferritic, so that, on cooling, the austenitic portions inverted to pearlite, as shown in Fig. 5, which also indicates partial breakdown of massive carbides. These carbides were present because the composition used for this light test piece was really suited to much thicker castings. As the temperature rose the depths of the various zones increased. Figure 6 shows the preferential oxidation proceeding along graphite flakes. In this specimen the centre was entirely pearlitic, since at the temperature of oxidation the matrix was fully austenitic. At 950° C., and particularly at 1050° C., oxidation was almost complete. The massive oxides formed on the specimen heated at 1050° C. are shown in Fig. 7. There are at least three phases, a dark-etching phase, possibly a silicate, a half-tone phase, and a lighter background, which itself appears to be duplex.

The low-alloy iron (*A.P.*) shows similar changes, though the zones were not as deep as in the unalloyed iron. Thus at 950° C. in the Ni–Cr iron the zone of heavy oxidation was 0·065 in. deep, whereas in the unalloyed iron it extended completely through the specimen, indicating that the alloys were more effective in retarding the spread of internal oxidation than in reducing the rate of external scaling. Figure 8, the Ni–Cr iron after scaling at 850° C., shows oxidation around the graphite flakes, which themselves appear to be replaced by a white metallic phase (*see* below).

The oxidation sequence was generally similar in the Silal specimens, which, as cast, showed traces of carbide in an almost entirely ferritic matrix and considerable fine graphite. The depth of attack was much less than in the low-alloy irons : at 950° C. the heavily oxidized portion was only 0·015 in. deep. It was remarkable that Silal did not show the same tendency to form a ' sub-scale ' by precipitation of fine oxide particles in the matrix, although the oxidation of Si would have been expected to cause precipitation of silica. The absence of oxide particles may be due to a slow rate of supply of oxygen. As in other irons, oxidation proceeded preferentially along the graphite flakes.

An unusual feature in Silal was a band apparently free from graphite beneath the heavily oxidized zone and the unaltered core. The band merely exhibited some coarse dispersed oxides and other non-metallic inclusions, together with some holes, Figs. 9 and 10. This may be due to a difference in the rates of diffusion of oxygen and carbon. The inward diffusion of oxygen is slow, whereas the outward migration of carbon caused by its oxidation and elimination at the surface may be relatively rapid. The rate of supply of oxygen would be insufficient to fill the holes with oxide, and the pressure arising from growth upon oxidation may actually close the holes. It is significant that the band formed only at 950° and at 1050° C. near the outside surface. Sometimes traces of a needle-like phase, probably carbides, were observed. These would be precipitated during the rapid cooling from the scaling temperature and would form as carbides because of the absence of residual graphite to nucleate the formation of fresh graphite.

The oxidation of the austenitic irons, such as Ni-Resist, presents several features of interest. The general sequence at 750° C. is illustrated in Fig. 11. Below the actual scale layer is a layer of mixed massive oxide, replacing original graphite flakes, and a surrounding matrix with much precipitated oxide, Fig. 12. In the next zone oxidation has proceeded preferentially along the graphite flakes, leading to oxide precipitation in the surrounding matrix, Fig. 13. In the interior of the metal, where no obvious oxidation had occurred, the original massive carbides became partially broken up and dissolved in the surrounding austenite, being precipitated during subsequent cooling (*cf.* Fig. 18 on Nicrosilal).

At 850° C. the Ni-Resist showed the same sequence of attack, as illustrated in Fig. 14. The outer zone, containing much massive oxide, is shown in Fig. 15. Figure 14 shows that this is followed by a band in which the original graphite flakes appear to have been replaced by a white metallic constituent. This is illustrated in Fig. 8, on the low Ni–Cr iron, and has been observed in specimens examined after exposure to service conditions. In the present investigation the ' metallic ' flakes were noted in the hematite and low Ni–Cr irons and in the austenitic irons, but not in Silal.

The apparent metallic flakes, Fig. 16, were usually surrounded by a heavily oxidized matrix, but did not themselves show any precipitate of fine oxides. In Ni-Resist these metallic flakes often showed a duplex structure, one constituent appearing to be rich in copper. These two constituents are difficult to show photographically. Deep-etching of the structure failed to clarify the nature of these flakes, but they were resistant to attack and remained bright, while the surrounding matrix was very deeply etched. They occurred to some extent in the samples oxidized at 750° (Fig. 13), 950°, and 1050° C., but reached their maximum development at 850° C.

The evidence suggests that they are of a metallic character and are higher in alloy content than the original iron. They may form under a relatively slow rate of oxygen supply, when the graphite is oxidized and resulting gases are able to diffuse away, leaving spaces into which the less oxidizable constituents of the matrix can diffuse. Since the surrounding matrix will already be oxidized to some extent, the incoming metal will be free from elements, such as Si and Mn, which are readily oxidized and precipitated as oxides. Diffusion of metal outwards through a scale layer is well recognized and, while it is difficult to see how metallic iron could diffuse through a region high in oxide and appear in a relatively pure state on the far side of the apparent surface of the oxide film, it is possible that the less oxidizable elements, such as Ni and Cu, could so diffuse and form a high-alloy solid solution which would be considerably more resistant to oxidation

than the surrounding matrix. This process occurs only at a relatively narrow range of temperature where the rate of supply of oxygen is not very high. At the higher temperatures the solid solution can never form in any appreciable quantity as the alloy elements are themselves rapidly oxidized. The white flakes may also be due to infiltration of a liquid phase such as a phosphate (*cf.* Tylecote*), when their absence at high temperature would presumably be due to decomposition of the phosphate.

At higher temperatures oxidation is more rapid and may be accompanied by complete decarburization, leading to the formation of a martensitic structure by breakdown of the impoverished austenite during cooling, *see* Fig. 17, which also shows the relatively small formation of the white phase on the site of the graphite flakes.

Ni-Resist of the higher Cr content was generally similar to normal Ni-Resist, apart from a larger amount of more stable carbides. At 850° C. a zone almost free from graphite, similar to that on Silal, was observed, also some of the white phase on the site of graphite flakes.

The oxidation sequence in Nicrosilal was very similar to that in Ni-Resist, with perhaps an even greater amount of solution and precipitation of carbide in the unoxidized centre of the specimen heated at 750° C., Fig. 18. Since the specimens heated to 950° and 1050° C. showed no precipitated carbide it appears that the precipitation at 750° C. actually occurred at that temperature, rather than during cooling. The microstructure of the specimens oxidized at 850° and 950° C. did not clarify the anomalous scaling rate in this temperature region, though the scale on the 950° C. specimen was particularly compact and resisted hammering. This might indicate a more complete freedom from fissuring than in the scale formed at 850° C. At 1050° C. the oxide scale showed three clear phases, a light-etching oxide, a dark-etching silicate, and considerable quantities of a metallic solid solution interspersed through the oxide, Fig. 19. The higher-Cr Nicrosilal was similar.

In the 16% Cr iron Enduron, there was very little indication of penetration of oxide at temperatures up to 950° C., though there were changes in the amount of precipitated carbide. The hardness of the 950° C. specimen increased from 289 to 610 Vickers, owing to austenite transformation on cooling. At 1050° C. there was some penetration of oxidation along the massive carbides, Fig. 20, probably due to diffusion of oxygen along the interface of the carbide and the matrix.

The 33% Cr iron microstructure was similar to that of the 16% Cr iron, consisting of massive carbides in a ferritic matrix. The only indication of oxidation on these specimens was a thin decarburized surface layer at 1050° C., Fig. 21. This iron does not form austenite and hence does not harden on cooling, but at 850° and 950° C. small amounts of a new phase in needle form, sometimes crossing each other, appeared in the matrix, usually remote from the carbide, Fig. 22. Experiments (unreported) suggest strongly that this new phase is sigma. The corresponding Ni-containing high-Cr iron had a similar microstructure. There was no evidence of sigma formation, but some precipitation of carbide occurred at 850° C., increasing the hardness to 330 Vickers.

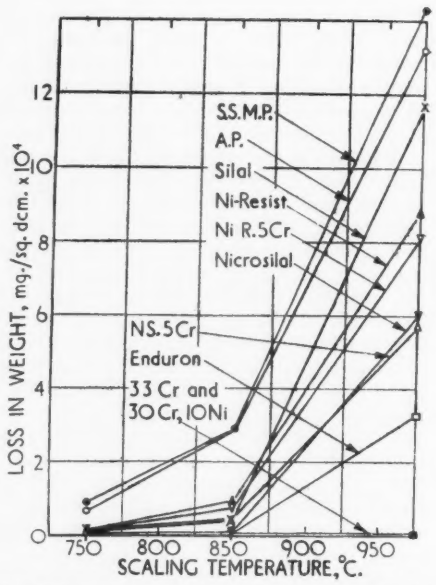

Fig. 25—Comparative scaling after nine cycles of 2 hr. in highly sulphurous, mildly oxidizing atmosphere

SCALING TESTS IN MILDLY OXIDIZING SULPHUROUS ATMOSPHERES

To imitate the conditions which may arise during operation of solid-fuel-fired furnaces and to produce conditions which were designed to be extremely unfavourable, tests were carried out in a gas-fired furnace, in which the products of combustion of town gas, with a substantial addition of sulphur dioxide, were passed over the specimens. The amount of secondary air admitted was kept as low as possible, compatible with holding the temperature, in the hope of maintaining some free carbon monoxide in the furnace and so reducing the intensity of the oxidation. It was thought that, under these conditions, the greatest opportunity would be given for the formation of sulphides of low melting point, particularly in the high-Ni irons.

There was considerable variation in the furnace atmosphere. Gas analyses were carried out at intervals, and typical results are recorded below :

Composition of Furnace Atmosphere

CO, %	CO_2, %	O_2, %	H_2S + SO_2, %
Nil	8·5	1·9	1·4
3·2	7·0	Nil	1·5
2·2	9·4*	1·4	...
0·4	9·1*	1·5	...

* Including H_2S + SO_2

The conditions were, on the whole, more strongly oxidizing than was intended, and the best that can be said of the variations is that they may reflect the conditions in some industrial furnace operations.

* R. F. Tylecote, *J. Inst. Metals*, 1950, vol. 78, p. 301.

To observe the effect of repeated heating and cooling, specimens were placed in the furnace, as in the earlier tests, raised to the test temperature, heated for 2 hr., and removed and cooled in air. They were then hammered to remove the scale and replaced in the furnace. After nine 2-hr. cycles of heating the specimens were finally hammered free from scale and the loss in weight was determined. The temperatures were 750°, 850°, and 975° C. The results are plotted in Fig. 25.

The order of merit of these specimens is almost identical with that for the tests in air. The small addition of Ni and Cr to the hematite iron does not appear to have been quite so effective in improving its resistance to scaling in the sulphurous atmosphere as in air. Silal is good up to 850° C., but at 975° C. its relative resistance has decreased. It appears that the more rapid deterioration which set in in some of the specimens at 1050° C. in air has set in at 975° C. in the sulphurous atmospheres. The relative merits of the high-Ni irons have not been affected by the sulphurous atmosphere and, as in the low-alloy irons, extra Cr has not been particularly valuable, but the high-Cr irons have maintained their extremely good resistance to oxidation at all temperatures studied. These results are probably due to too much free oxygen in the furnace atmosphere.

Microstructure

Most of the features observed on the specimens oxidized in air were noted also in this series, including the replacement of graphite flakes by the white phase in several of the irons. No clear indications of sulphides were detected, and the scale structures were much as before. Fig. 23 (*cf.* Fig. 5).

TESTS ON SENSITIVITY TO CRACKING

Cracking is one of the most serious service troubles of heat-resisting cast iron and, rather than its resistance to scaling, often determines the life of the part. Tests were made to study the relative susceptibility of the different irons to cracking, using small box-shaped castings with external dimensions of $5\frac{1}{2}$ in. long × $3\frac{1}{2}$ in. wide × $2\frac{3}{4}$ in. deep. The wall thickness was $\frac{1}{4}$ in. and the boxes were cast with an open top. The boxes were of a section too light for the hematite iron and the 1·0% Ni–Cr iron, which normally have wall thicknesses of at least 1 in. Hence, the boxes in these materials contained a higher proportion of massive carbide than would normal castings in practice.

Four different test cycles were applied : (1) The boxes were heated to 700° C. and then quenched individually in cold water. This temperature avoided the complication of stresses arising from austenite decomposition during the quenching operation. (2) Individual specimens were placed on the hearth of a large furnace at 1000° C. so as to heat up very rapidly. As soon as they had attained the furnace temperature they were removed and cooled in air on a cold cast-iron floor plate. This was repeated for 15 cycles. In this test emphasis was placed on speed of heating, as it is felt that much of the cracking in iron castings in service occurs during heating, rather than during cooling. (3) Boxes were filled almost instantaneously with molten cast iron from a cupola at a temperature of 1300–1330° C., held for some 5 sec., and the molten iron was then tipped out and the box was air-cooled. This was repeated six times. (4) As a final test, boxes were passed through a continuous annealing furnace, which rose to a temperature of about 980° C. in about $1\frac{1}{2}$ hr., after which the boxes were held for $1\frac{1}{2}$ hr. at temperature and cooled to room temperature in 10 hr.

The results of all these tests are summarized in Table III, where for each condition of testing the number of cycles leading to the formation of the first crack is noted.

The continuous-furnace tests are obviously not very severe, and the cracking of the hematite iron and the 1% Ni–Cr iron is due to excessive scaling rather than to thermal stresses. Silal was the most brittle material in each test, but surprisingly the 33% Cr irons resisted cracking in all cases. The relatively poor resistance of *S.S.M.P.* (the hematite iron) and of *A.P.* (1% Ni–Cr) may be connected with the unusually high proportion of massive carbides in the microstructure. The austenitic irons, in particular

Table III

SUMMARY OF RESULTS OF CRACKING TESTS ON BOX CASTINGS

Material	No. of Cycles to First Cracking*			
	W.Q. 700° C.†	A.C. 1000° C.‡	Molten Metal§	Continuous Furnace‖
S.S.M.P.	1	11	1	3
A.P.	4	U(5)	1	19
Silal	1	4	1	U
Ni-Resist	5	U(4)	U	U
Ni-Resist (5 Cr)	1	U(6)	4	U
Nicrosilal	U	U	U	U
Nicrosilal (5 Cr)	6	U(8)	U	U
Enduron	5	U	...	U
33 Cr	U	U	U	U
30 Cr, 10 Ni	U	U	U	U

* U = Unbroken
† Quenched in cold water from 700° C., six cycles
‡ Placed in large furnace at 1000° C. for maximum speed of heating, cooled in air on cold cast-iron floor plate ; 15 cycles. Figures in brackets indicate change in ' ring ' but no visible cracks
§ Molten cast iron at 1300–1330° C. poured into box, held for 5 sec., tipped out and air-cooled ; six cycles
‖ Passed through continuous furnace at 980° C., rising to temperature in $1\frac{1}{2}$ hr., soaking $1\frac{1}{2}$ hr., and cooling in 10 hr.

Ni-Resist, did not behave as well as would be expected. The evidence suggests that a higher Cr content, associated with a larger proportion of carbides, increases the sensitivity to cracking. These tests cannot be regarded as highly satisfactory, but they at least bring out the thermal brittleness of Silal and the unexpectedly good behaviour of 33% Cr irons.

CONFIRMATORY SERVICE TESTS

To check the laboratory results against results obtained in service, a series of furnace base plates and covers of the design indicated in Fig. 24, were cast from the same ladles of metal as those used for the test bars for scaling. These were employed in a continuous furnace, the base plate sliding on skid bars and carrying on its upper surface the centrifugal casting being annealed, which, in turn, was enclosed in the protective cover. On entering the furnace the base plate and cover came immediately into contact with producer-gas flames and were heated fairly rapidly to 1020° C. They remained at this temperature for 2 hr. and cooled gradually through the remaining portion of the furnace, being ejected after 8 hr. while at a temperature of about 600° C. The furnace was fitted with an accurate temperature control.

Only the more heat-resisting irons were included in this series, *viz.*, Ni-Resist of a higher Cr content, both types of Nicrosilal, and the various high-Cr irons, as the lower-alloy materials were obviously unsuitable for such high temperatures. Five base plates and five covers were cast in each material.

The results are summarized in Table IV. The Ni-Resist samples were excessively scaled after 119 cycles through the furnace ; the Nicrosilal irons and Enduron reached a similar state after 145 cycles, whereas the high-Cr irons were still capable of considerable service after 242 cycles.

All three of the austenitic irons of relatively low Cr content showed cracking, though this was generally only after severe scaling had occurred. The 5% Cr austenitic irons appear to be more prone to cracking than the corresponding irons of normal Cr content. On the other hand, almost no cracking occurred in the straight-Cr irons at either the 16% or 33% levels. The addition of 10% of Ni to the 33% Cr iron has proved disappointing, two of the covers and five of the base plates showing cracking after long service. The cracks in the base plates were usually adjacent to a strengthening rib at the side of the base plate.

The indications of the laboratory tests, both on cracking and on general scale resistance, are confirmed fairly satisfactorily by these service tests. After this experiment the 33% Cr iron was standardized for replacements and gave continuously satisfactory service.

The good performance, both in cracking tests and in service, of this material, which is considered to be prone to cracking, is believed to be due to the very thin section of the cover, and to a lesser extent the base plate, preventing the building up of large thermal stresses. There seems to be a definite scale effect in the liability of this material to failure by

Table IV

RESULTS OF SERVICE TESTS ON ALLOY CAST IRONS AT 1020° C.

No. of Cycles through Furnace	Ni-Resist H.C.	Nicrosilal	Nicrosilal (5 Cr)	Enduron	33 Cr	30 Cr, 10 Ni
			Covers			
16	MS, 0C, 0D	SS, 0C, 0D	SS, 0C, 0D	VSS, 0C, 0D	VSS, 0C, 0D	VSS, 0C, 0D
70	HS, 1C, 0D	MS, 0C, 0D	MS, 1C, 0D	SS, 0C, 0D	SS, 0C, 0D	SS, 0C, 0D
82	VS, 1C, ID	HS, 0C, 0D	MS, 2C, 0D	MS, 0C, 0D	SS, 0C, 0D	SS, 0C, 0D
119	X, 4C, 4D*	VS, 0C, 0D	HS, 2C, 0D	HS, 0C, 0D	SS, 0C, 0D	SS, 0C, 0D
145	...	X, 4C, 4D	X, 4C, 4D	VS,† 0C,† 0D†	SS, 0C, 0D	SS, 0C, 0D
170	...	...	...	...	SS, 0C, 0D	SS, 1C, 0D
181	...	...	...	...	SS, 0C, 0D	SS, 1C, 0D
198	...	...	...	...	SS, 0C, 0D	SS, 1C, 0D
242	...	...	...	...	SS, 0C, 0D	SS, 2C, 0D
			Base Plates			
16	MS, 0C	SS, 0C	SS, 0C	VSS, 0C	VSS, 0C	VSS, 0D
70	HS, 0C, 0D	MS, 0C, 0D	MS, 3C†, 0D	SS, 0C, 0D	SS, 0C, 0D	SS, 0C, 0D
82	VS, 0C, 0D	HS, 0C, 0D	MS, 0C, 0D	MS, 0C, 0D	SS, 0C, 0D	SS, 0C, 0D
119	X, 4C, 4D*	VS, 4C, 0D	HS, 0C, 0D	HS, 0C, 0D	SS, 0C, 0D	SS, 0C, 0D
145	...	X, 4C, 4D	X, 4C, 4D	VS,† 0C,† 0D†	SS, 1C, 0D	SS, 0C, 0D
170	...	...	...	...	SS, 1C†, 1D	SS, 5C, 0D
181	...	...	...	...	SS, 0C, 0D	SS, 5C, 0D
198	...	...	...	...	SS, 1C, 0D	SS, 5C, 0D
242	...	...	...	...	SS, 1C, 0D	SS, 5C, 0D

* Scrapped at 90 cycles
† Scrapped at this stage

VSS = very slight scaling
SS = slight scaling
MS = medium scaling
HS = heavy scaling
VS = very heavy scaling
X = scrapped by scaling

C = cracked
D = distorted
} Preceded by number of samples showing this defect

thermal stresses. In other furnace tests, rectangular plates, approx. 2 ft. sq. × $\frac{3}{8}$ in. thick and cast in 33% Cr iron, were used as base plates for supporting castings in a bogie type of annealing furnace operating at about 1000° C. Four castings were generally placed on each of these plates, but all the plates cracked completely across after only two or three annealing cycles. When the 2-ft. sq. plates were substituted by 6-in. sq. plates, each plate supporting only one casting, no cracking was experienced and the base plates have been in service for a matter of years. The base plates were completely unstressed and were not restrained in any way, simply resting on the refractory top of the furnace bogie. It seems that there is a greater liability to build up dangerous stresses in large castings than in small ones.

Acknowledgments

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A Gas-Tight Device for Measuring Blast-Furnace Stock Level

By D. R. Brown, B.A. and C. E. Wilson

SYNOPSIS

The escape of gas at the gland through which the stock rod is raised or lowered, when measuring the level of the burden in a blast-furnace, has been prevented by enclosing the moving parts in a gas-tight container. The device has proved effective on a furnace operating at high top pressure.

THE leakage of gas through the normal design of stock-rod sleeve at the blast-furnace top platform level is a nuisance that has led to unceasing investigation by operators and engineers, yet none of the methods of sealing developed, employing glands of various types in this location, can be regarded as completely satisfactory. In fact, it is almost impossible to produce an efficient seal of the gland type under the conditions which obtain, *i.e.*,

(i) The length of travel of the rod (usually about 5 or 6 ft., up to a maximum of 20 ft.)
(ii) Friction must never be excessive, since the effective weight of the stock rod is a vital feature of the control of the recording mechanism
(iii) A bright, smooth surface, such as is essential for efficient gland sealing, cannot be maintained on the rod owing to the hot dust-laden gas in which it works
(iv) It cannot be expected that the rod will remain axially true on account of its own unguided length working under the conditions mentioned above
(v) The position is further aggravated when it becomes necessary to seal a furnace working at high top pressure, for not only is there an increase in the volume of escaping gases but this dust-laden medium has a far more vigorous action in the destruction of the gland.

Recently, the proposal to convert a blast-furnace for operation at high top pressure provided an opportunity to develop in detail an idea that was already scheduled for attention.

All attempts to seal the rod in the orthodox manner were abandoned, and the gas was contained by a gland situated where it could operate under conditions best suited to this method of sealing. The equipment consists of a rising and falling rod and a similarly moving wire rope ; the character of the motion then changes as it is transmitted to a rotating drum on a spindle. If the sealing gland could be transposed to the rotating spindle it would not be difficult to make it gas-tight. Thus, the stockline recorder unit itself could be located in the structure immediately above the rod, and all moving parts, up to the drum, could be encased in a gas-tight container with a sealing gland on the spindle between the drum and the gear-box from which it is driven. The disadvantages of a unit in this position could be overcome if the drum within the pressure container moved in unison with a duplicate drum outside the container, the latter being driven by a wire line from the winch, located in the engine house or other suitable place. The shape of the pressure container further assists the problem because the gas at the gland is at a remote dead-end, away from the main stream in the furnace top and very considerably cooler than the furnace gas. This cooler, stagnant gas is infinitely less harmful to the sealing element than the gas that attacks the orthodox gland. The practical adaptation of these principles is shown in Figs. 1*a* and *b*.

Attached to the opening through which the stock rod enters the furnace by a normal gas-tight flange, is the long tube rising vertically above the furnace top for a distance sufficient to accommodate the rod when in the ' up ' position. This tube is large enough to allow the rod to work freely and in fact enables the weighted foot to be withdrawn into the tube. It is also provided with access ports at both ends. On top of the tube is an enclosed housing containing a grooved rope drum to which is fastened the rope carrying the rod. This drum is carried on a shaft which passes through a gas-tight sealing gland fitted in the wall of the housing and is extended to carry an exactly similar drum outside the housing. The seal (Fig. 1*c*) consists of segmental carbon rings held

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Mr. Brown and Mr. Wilson are Manager and Chief Designer respectively of the Blast-Furnace Construction Department of Messrs. Ashmore, Benson, Pease and Co., Stockton-on-Tees.

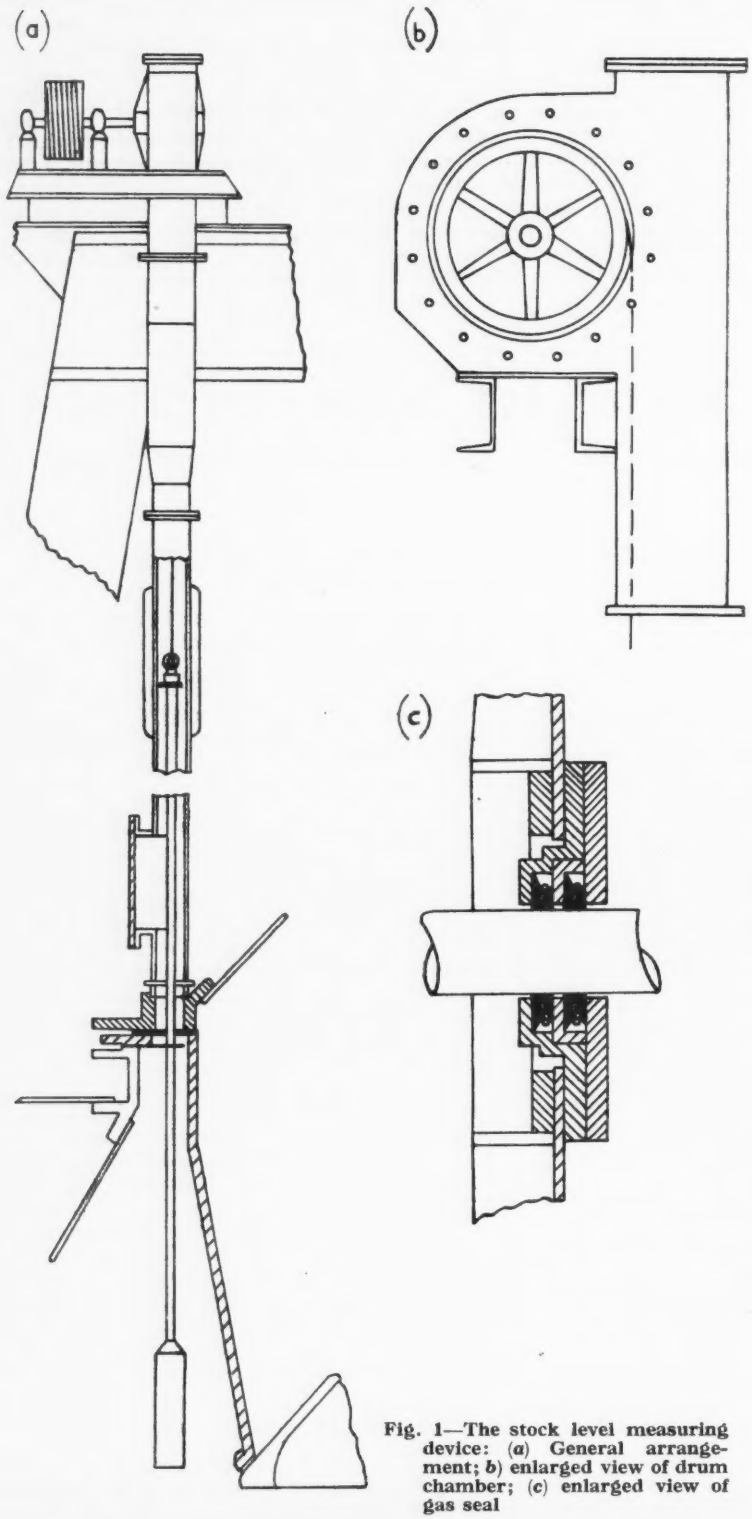

Fig. 1—The stock level measuring device: (*a*) General arrangement; *b*) enlarged view of drum chamber; (*c*) enlarged view of gas seal

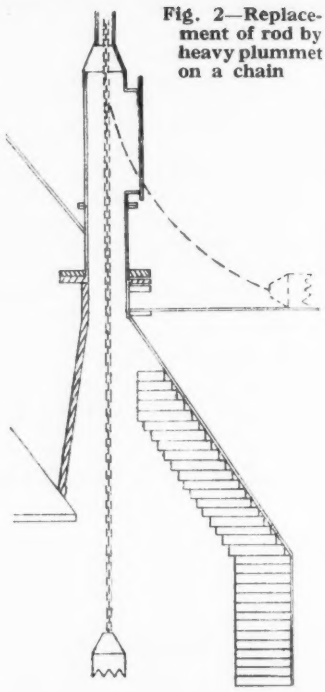

Fig. 2—Replacement of rod by heavy plummet on a chain

in position by garter springs and working on a polished hardened surface of the shaft.

The outside drum is connected by a separate wire rope passing over the normal guide pulleys down the skip bridge to the stockline winch and recording mechanism. Figure 1*b* shows an enlarged arrangement of the top housing, which also provides means for withdrawing the rod or introducing a new one, by removing the cover-cap. This equipment has been fitted to the No. 2 furnace at Clyde Iron Works and has proved entirely satisfactory. After 12 months' working it has needed no attention apart from normal lubrication.

Once the principle of a glanded rod has been forsaken it is no longer necessary for the depth-measuring medium to be a solid bar. A heavy plummet on a chain, or other flexible suspension can be substituted for the rod and the whole device can be still further simplified, particularly the operation of changing the parts that enter the furnace, as can be seen in Fig. 2.

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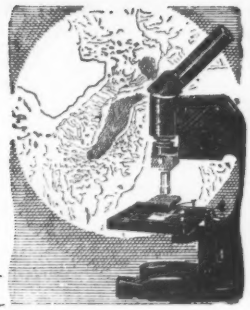

The Deformation of Low-Carbon Steel in the Blue-Brittle Range

By E. O. Hall, M.Sc., Ph.D.

SYNOPSIS

A study has been made of the deformation of Bessemer and Armco iron wires and thin strip, at temperatures in the region of 150–250° C. It is shown that the jagged stress/strain curves that are obtained arise from the interrupted propagation of the fronts of the Lüders bands, and from the formation of new ('secondary') bands in strain-aged material. Certain of these stress fluctuations can be suppressed at high strain rates.

The importance of the use of thin strip and wire in the investigation of the Lüders deformation in mild steel is emphasized.

THE stress/strain curve of a specimen of mild steel tested at a slightly elevated temperature becomes very jagged, and the elongation to fracture of the specimen is markedly less than at room temperature. This is the phenomenon of 'blue-brittleness.' The name is misleading, for the fracture is of the normal (ductile) type and not a brittle (cleavage) fracture. Previous work (for example, Kenyon and Burns[1]) has shown that the decreased ductility and the irregular stress/strain curve are the result of strain-ageing occurring during the tensile test.

An investigation of the Lüders deformation of mild steel has been carried out at the Cavendish Laboratory over the past few years,[2–4] and the research has recently been extended to the blue-brittle range. The results of these experiments are given in this paper.

APPARATUS AND MATERIALS

The testing frame used in the experiments has already been described.[2] The method of measuring the stress is shown in Fig. 1. The upper grip is connected to a 0·04-in. thick spring steel plate, the deflection of which is measured by a dial gauge. The machine is made autographic, because the load fluctuates rapidly during the tests. From the top of the dial gauge, cotton thread runs over an axle which carries a mirror. Under load, the mirror rotates and deflects a beam of light, which is focused on a rotating drum camera, about 5 ft. from the extensometer. These deflections may be calibrated by direct loading. The whole system has very low inertia, and is most suitable for recording rapid variations in load.

Specimens of Armco iron and a basic Bessemer steel were used in the form of 1-mm. dia. wire or 2 × ½ mm. strip. The analyses are given in Table I. The wire was cut from coils, annealed *in vacuo*, and then furnace-cooled, and general stress/strain investigations were carried out. However, Lüders bands are difficult to see and almost impossible to photograph on wires, and it was therefore necessary to prepare thin strip specimens, by rolling down 2-mm. dia. wire to ½ mm. thickness. A gauge length 2 mm. wide × 14 mm. long was milled from the strips, and the specimens were then annealed. After this treatment the strips were wet-polished down to 600 'Hydrodurexsil' paper, and were finally electropolished in the bath described by Morris.[5] The gauge length of all the specimens, after clamping in the grips, was 100 mm.

Heating Arrangements

Because of the small size of the specimens, it was possible to heat them electrically with currents of 7–12 amp. The resulting temperature distribution, however, was not uniform. Heat was conducted away to the heavier grips at the ends of the specimen, and there were additional losses from the surface of the wire by convection and radiation.

Temperatures were measured by a thermocouple attached to the wire. The distribution was not symmetrical, but there was a region about 4–5 cm. wide in which the temperature was within a 10° C. range, and accurate quantitative comparisons could

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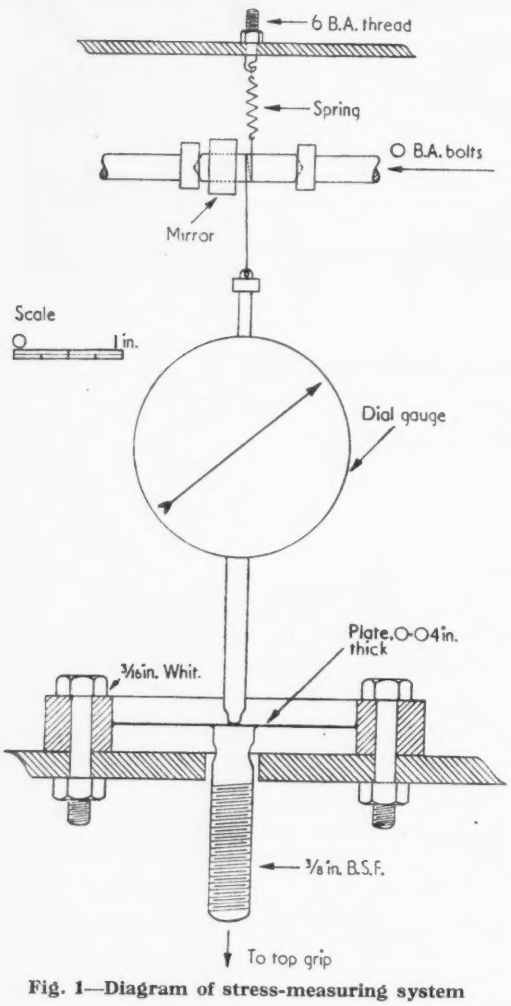

Fig. 1—Diagram of stress-measuring system

be made. In practice, ageing at temperatures above about 120° C. is so rapid in comparison with the strain rates used that significant results may be obtained from a much greater length of specimen.

RESULTS

Tests with Wire Specimens

Two typical autographic stress/strain records are shown in Fig. 2. Figure 2*a* is from a specimen of basic Bessemer steel, in the form of 1-mm. dia. wire, which was annealed at 780° C. for 2 hr. *in vacuo* and then furnace-cooled. The specimen was deformed at room temperature at a strain rate of 0·0033/min. In normal heavy tensile test specimens the lower yield stress is very irregular, because a complex series of Lüders bands is formed along the gauge length, and the stress fluctuates each time a new set of band fronts is formed. However, the author has recently shown[3] that if wire or thin strip specimens are used deformation occurs by a single Lüders band, which appears from the stress concentration around one or other of the grips and spreads under virtually constant stress over the gauge length. Thus, using material of this size, accurate measurements of the propagation stress and Lüders strain are possible. In Fig. 2*a*, the stress concentration around the grips practically suppresses the upper yield point ; the lower yield stress is very uniform, and the band reaches the far grip at the point *A*. From there onwards, deformation is homogeneous.

The curve shown in Fig. 2*b* is for the same material from the same batch as for Fig. 2*a* and deformed at the same strain rate, but the wire was heated electrically so that the temperature at the middle of the wire was 205° C. Points to note are :

(i) There are two types of stress fluctuation during the test
(ii) The first (type *A*) occurs during the Lüders extension, and consists of a series of saw-tooth ' pips ' of remarkable regularity ; these would be completely masked if a heavy tensile specimen were used
(iii) Each ' pip ' consists of a fluctuation where the stress falls very rapidly and then rises with the same gradient as in the elastic region
(iv) The Lüders strain (the extension to the point *A*) is less than in Fig. 2*a*
(v) The lower yield stress is less than in the room-temperature test
(vi) The second type of fluctuation (type *B*) occurs after the Lüders extension, and consists of sudden small random drops in the load.

All the specimens tested showed this type of curve. The height of the pips varied inversely with the grain size of the specimens, and also varied with temperature. As the heating current was reduced, the effective hot zone in the centre of the wire was narrowed, and the number of ' pips ' decreased until, at about 100° C., there was only a rise in the propagation stress as the band front passed through the hot zone.

Tests with Strip Specimens

Specimens of Bessemer steel were uniformly treated to give a grain size of 4000–5000/sq. mm. Figure 3*a* shows a typical Lüders band in a strip specimen, which was extended at room temperature at the same strain rate, *i.e.*, 0·0033/min. The band, which has a single front, has spread uniformly from one grip over the gauge length, under a stress of $23{\cdot}1 \pm 0{\cdot}3$ kg./sq. mm. The upper part of the specimen is undeformed, and severe roughening of the surface has taken place in the deformed area.

These Lüders bands propagating through virgin material have been termed ' primary ' bands.[2] Similar bands, which occur in strain-aged material, have been termed ' secondary ' bands, and in fully aged specimens have the same appearance as primary bands.

Table I

ANALYSIS OF IRON SAMPLES

	C, %	S, %	P, %	Mn, %	Ni, %	Cu, %	Si
Armco	0·020	0·025	0·009	0·035	0·036	0·078	...
Basic Bessemer (Thomas quality)	0·045	0·047	0·04	0·33	...	...	Trace

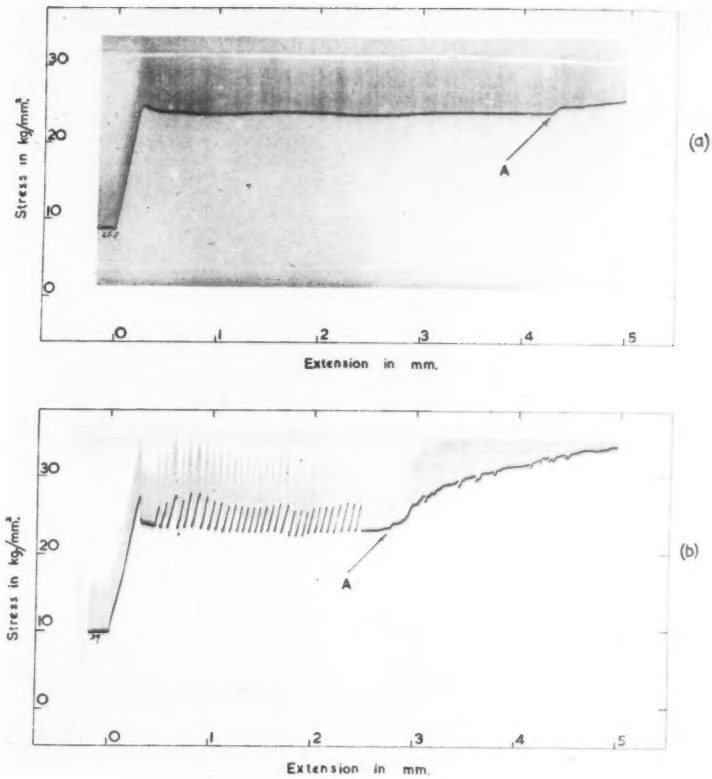

Fig. 2—Autographic stress/strain curves from wire specimens, strained (*a*) at room temperature ; (*b*) at 205° C.

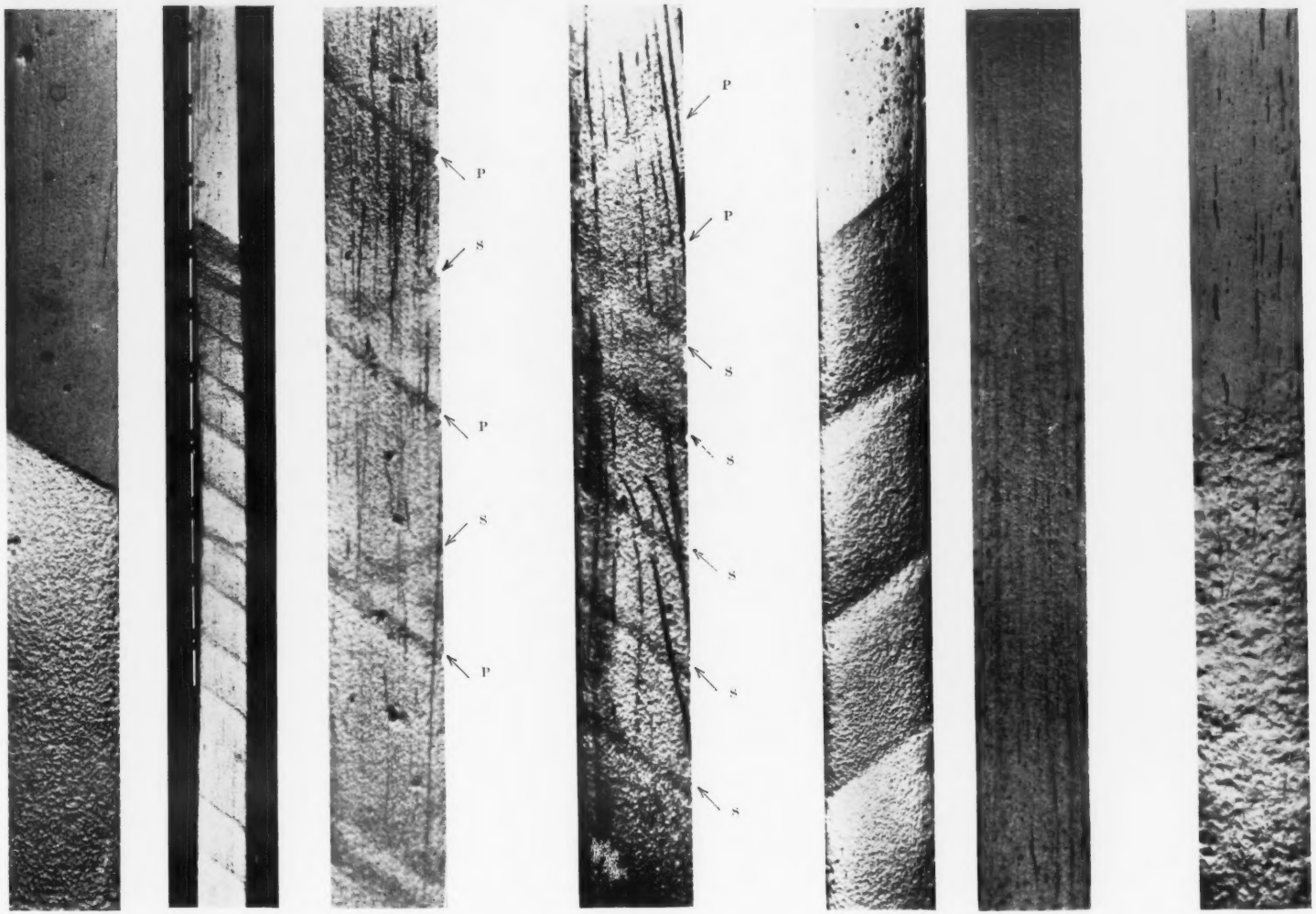

Fig. 3—Specimens of Bessemer steel: (*a*) Typical primary Lüders band at room temperature; (*b*) extended view showing 14 markings left by interrupted propagation of the primary band at 200° C. × 4; (*c*) primary markings *P* and secondary markings *S*; (*d*) primary markings *P* and active secondary bands *S*; (*e*) interrupted motion of a Primary band (fast test); (*f*) uniform motion of a primary band (fast test)

Fig. 4—Diffuse Lüders band in Armco iron

It has been found possible to interpret the two types of stress fluctuation in terms of the movement of the primary and secondary Lüders fronts. When a strip is strained at temperatures around 200° C., the band can be watched as it moves out from the grip. At first, the band moves uniformly and spreads over the specimen for a distance of about 2 cm. As it runs into the hotter zone, however, the front suddenly stops, and the stress begins to rise in the first of the saw-tooth ' pips ' seen in Fig. 2*b*. Then, at a certain stress, the band is seen to suddenly dart forward, and simultaneously the stress falls. The band front moves forward a distance of about 3 mm. before it slows down sufficiently to be locked again, and the whole process is then repeated, because as soon as the front stops, the stress will rise at the same rate as in the elastic region. The velocity of the band front immediately after its release is difficult to measure, but it has been estimated (by eye) to be between 1 and 10 cm./sec., a very much higher value than in any room-temperature test at the same strain rate.

When the band moves forward it leaves a mark on the surface of the specimen, which indicates the position in which it was locked. Thus, at the end of the primary Lüders extension the specimen is covered with a series of parallel markings. A specimen with 14 markings visible is shown in Fig. 3*b*. The deformed area of the specimen possesses a marked curvature—not observed in room-temperature tests, where there is evidence only of an angular kink at the edge of the band. Thus, in tests in the blue-brittle range, it appears that mild steel may be bent by straining in tension. The radius of curvature of the specimen in this state is nearly 1 metre, so that a macroscopic strain inhomogeneity of 0·2% has been induced between the two sides of the specimen.

The mean Lüders strain over the gauge length between the markings may be determined from the following data, typical of this batch of specimens :

Mean upper yield point	...	27·1 kg./sq. mm.
Mean lower yield point	...	21·5 kg./sq. mm.
Mean time interval between pips		16 sec.
Mean distance between markings		3·0 mm.
Strain rate		0·0033/min.

In 16 sec., the straining head moves $(\frac{16}{60} \times 0{\cdot}33)$ mm.

$$\therefore \text{Mean strain} = 16 \times 0{\cdot}33/(60 \times 3{\cdot}0) = 2{\cdot}9\%.$$

This value is about 1·4% lower than in the room-temperature test.

About 1 cm. from the far grip, the band comes out of the hot zone and propagates uniformly over this distance. The stress then rises, but the material has by now strain-aged over its entire length and so must deform by secondary Lüders bands.

The appearance of the secondary bands in these strip specimens is necessarily complicated, because of the uneven temperature distribution ; it must be emphasized, however, that even if the temperature were uniform the specimen could no longer be considered in such a ' homogeneously strained ' state at the end of the primary extension as it is in a room-temperature test, because one end of the specimen has had considerably more time to strain-age than the other.

There are two types of secondary band markings which appear at this stage in the tensile test, and the appearance of each type is accompanied by a small drop in load. The first type is shown in Fig. 3*c*. In addition to the remains of the primary front markings (*P*), it is seen that other markings (*S*) have arisen which must be ascribed to secondary band formation. They are apparently very narrow bands of deformation, which cause only a small drop in load. Later, there also appears, usually from one or other of the grips, a true *broad* secondary band, which propagates in jerks and leaves another series of parallel marks on the specimen (*see* Fig. 3*d*) in exactly the same manner as does the primary. The spacing of these marks is a little smaller than for the primary ones, and each movement of the front gives rise to a larger stress fluctuation than do the other narrow secondary bands. The stress fluctuations observed in the autographic records are thus associated with either the interrupted motion of the primary band fronts (type *A*) or the formation or interrupted propagation of the secondary band (type *B*).

The Effect of Varying Strain Rate

The fact that the primary band, on release, can propagate a distance of about 3 mm. before it slows down sufficiently to be locked again, raises an interesting problem. The velocity of the band front may be raised by increasing the strain rate, and it was thought that, if the strain rate were raised sufficiently, the band front might be able to propagate right through the specimen without being locked at all.

A further series of experiments showed that, at high strain rates, the type *A* stress fluctuations could be entirely suppressed. Figure 3*e* is a photograph of a strip of Bessemer steel, deformed at 200° C. with a straining-head velocity of 4·3 mm./min., and with the expected surface markings. With a straining-head velocity of 4·5 mm./min. (Fig. 3*f*), there is no sign of any surface markings but only a uniform surface roughening, and the stress/strain curve is quite smooth ; it is evident that the front of the Lüders band is moving so rapidly that it can avoid the effect of the material strain-ageing just behind it. Under these testing conditions the critical velocity of the Lüders front was found to be 2·5 mm./sec., and this must also be the velocity at which the band is suddenly locked in its interrupted propagation at lower strain rates. The velocity of a band observed at the same strain rate but at room temperature was 1·4 mm./sec.

The initial strain rate for the suppression of the type *A* stress fluctuations should depend on two variables—the temperature of the test, since this determines the rate of strain-ageing, and the grain size of the specimens, since the Lüders fronts move more quickly through coarse-grained material.

The Effect of Varying Grain Size

As already shown,[4] the grain size largely determines the properties of the specimens used. The blue-brittle tests on wire specimens also show that the size of the

type *A* stress fluctuation was smaller as the grain size of the specimen increased.

In strip specimens, the effect of increasing the grain size is to decrease the clarity of the type A surface markings. The jerky movement of the band front, however, is still observed, and still coincides with the sudden drop in stress, even though the markings may be invisible.

Figure 4 shows a specimen of Armco iron, with a grain size of 480/sq. mm., deformed in a hot test with a cross-head velocity of 0·33 mm./min. The grain size is so large that the sharp shear kink at the front of the Lüders band has disappeared, and consequently the band is 'diffuse,' with rather different properties from the 'sharp' bands in fine-grained material.[3] Although the movement of the front was still irregular, with stress fluctuations of 1·5 kg./sq. mm., no markings can be seen in the photograph.

DISCUSSION

The lower yield stress in a blue-brittle test is markedly lower than that in a room-temperature test, because the yield point of iron is extremely sensitive to temperature[6, 7] provided that ageing is slow compared with the deformation rate. Secondly, the stress peaks observed during the passage of the primary band are similar to those observed in ageing experiments in room-temperature tests.[2] In the blue-brittle tests reported in this paper, ageing and deformation occur together, so that at low strain rates the area just behind the band front has a yield stress above that of the applied (lower yield) stress. The dislocations therefore cannot move through the strained material as it deforms, and so cannot build up the dislocation arrays which, by their stress concentrations, break down the still undeformed material. To do this, either the stress must reach a value such that a local secondary band is formed just behind the locked front,[2] or sufficient stress must be supplied to move the dislocations up to the locked front and so cause the boundary to break down.

Once the front of the Lüders band is released, the front propagates into unstrained material; at the same time, the specimen is under a much higher stress than the normal propagation stress for the Lüders front at this temperature, and so can move much more rapidly than is normal. As the stress falls the band slows down, and the effect of the strain-ageing soon blocks the movement of the dislocations through the matrix. The band stops, and the process is repeated. The same argument applies to the movement of the secondary fronts in strain-aged material.

The variation of strain between the locked positions of the band cannot be determined from the relation $\varepsilon = V/v'$ (where ε is the Lüders strain, V is the straining-head velocity, and v' is the velocity of the band front[2]), because the elastic contractions taking place during the variation of the load have to be considered. It is shown in the Appendix that the strain is greatest immediately after the front is released, and decreases as the front slows down again. Furthermore, the variation in strain resulting from the irregular movement of the front is presumably the reason for the marks left behind on the surface, since they are the indication of varying lateral contractions.

In coarse-grained material, the variation of ε between the locked positions of the front is much less, because the variation of v' between these points is small. Hence, it becomes progressively more difficult to observe the marks as the grain size is increased.

The macroscopic curvature induced in these specimens by the Lüders deformation (*see* Fig. 3*b*) appears to follow from a previous theory of the lower yield point[3] which suggests that the Lüders bands in mild steel could each be characterized by a uniform shear front. The shear displacement at the band edge is straightened by the constraint of the grips through plastic bending, as the yield stress of the deformed material is no higher than the applied (lower yield) stress. This leaves only an angular kink of about 2° at the edge of the band. The deformed and undeformed areas are no longer coplanar, but otherwise are straight.

In these experiments the shear displacement cannot be straightened by plastical work, because as soon as the material deforms, it strain-ages rapidly at these temperatures and its yield stress soon exceeds the applied stress. Thus, on unloading the specimen a marked curvature is seen.

The form of the secondary bands appearing after the primary deformation is greatly influenced by this macroscopic curvature. The first type noticed (the narrow *S* bands, Fig. 3*c*) merely assist in straightening the bend in the specimen, and consequently they do not spread far. The direction of their fronts agrees with this observation. When the specimen is sufficiently straightened by nucleating a number of these bands, a true secondary band appears from one or other of the grips and propagates in jerks exactly as does the primary band (*see* Fig. 3*d*).

The Effect of the Testing Machine

Testing machines are usually divided into two types, soft and hard. In the soft machines the load is effectively supplied by a soft spring, so that the value of the stress does not change appreciably with any sudden extension of the specimen. In hard machines, as used in these tests, the specimen is rigidly connected to the stress-measuring system; a sudden small extension of the specimen gives rise to a very large relaxation of the stress, but deformation ceases when the stress falls to the yield stress of the material. In normal metals, where the stress/strain curve is smooth, the two types of machine give identical results, but in tests on mild steel or on certain aluminium alloys, where the stress/strain curve shows many irregularities, the two types of machine give entirely different results.

On materials of the type used in these tests, supposing that the stress concentrations around the grips have entirely suppressed the primary upper yield point (*see* Fig. 2*a*), yielding will begin and continue at the lower yield stress, until the band runs into the hot zone of the specimen. The stress would then have to be increased until the peak stress of the 'pip' was reached, when the band would propagate right through the specimen at a very high velocity and no further stress peaks would be observed. This result also

follows from the analysis given in the Appendix. The main variation in the results obtained using the two types of machine would be in the spacings of the surface markings left on the specimen by the interrupted movement of the primary band. The spacing would range from about 3 mm. with the very hard machine used in these tests, to infinity in the very soft machines. Hard machines will give the more realistic picture of the yield stress of the material at any stage of the deformation.

Finally, there is the effect of inertia in the testing machine. In many commercial machines, where the load is indicated by a pendulum arrangement, any stress fluctuations are greatly magnified by the oscillations of the system, the natural period of oscillation being of the same order as the interval between the fluctuations. The advantages of testing specimens of small cross-section are evident, because (apart from deformation occurring by a single Lüders band) the small loads required allow simple and light stress-measurement systems to be employed, and inertia is cut to a minimum.

Acknowledgments

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APPENDIX

The Luders Strain under Varying Load

For an analysis of this problem, consider the testing machine to be composed of the elastic and plastic elements shown in Fig. 5.

During the motion of the Lüders front, a length δl of the specimen becomes $(1 + \varepsilon)\delta l$ in a time interval δt. Equating this extension to the cross-head movement and the contraction of the elastic elements :

$$\epsilon\delta l = V\delta t + \left(\frac{1}{k} + \frac{l}{E}\right)\delta\sigma,$$

where ε is the Lüders strain and $\delta\sigma$ is the fall in load in the time interval δt. In the limit :

$$\epsilon = \frac{V}{v'} + \frac{A}{v'} \cdot \frac{d\sigma}{dt} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where v' is the velocity of the band front, and $A = \frac{1}{k} + \frac{l}{E}$.

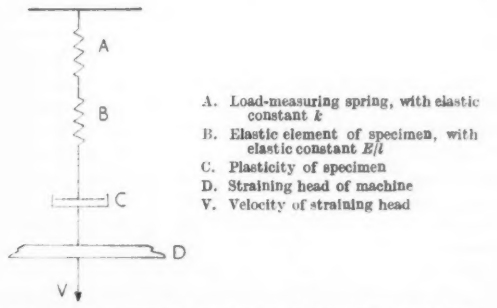

Fig. 5—Mechanical analogue of testing machine

When σ is constant, equation (1) reduces to the steady state condition that $\varepsilon = V/v'$.

To solve equation (1), both σ and ε must be known in terms of v'. These measurements have not yet been made in the blue-brittle range, but an investigation at room temperature indicates that a fair approximation is given by :

$$\sigma = a\log(v' + v_0) + b$$
$$\epsilon = \alpha + \beta v'$$

where a, b, v_0, α, and β are constants. Substituting in equation (1) :

$$\frac{dv'}{(v' + v_0)(\beta v'^2 + \alpha v' - V)} = \frac{dt}{Aa}.$$

After reduction, the solution of this equation is :

$$\left(1 - \frac{p}{v'}\right)^q \left(1 - \frac{q}{v'}\right)^{-p} = Be^{\frac{-(p-q)V}{Aa} \cdot t} \quad \ldots\ldots\ldots (2)$$

where p and q are the roots of the quadratic $\beta v'^2 + \alpha v' - V = 0$, B is a constant, and it has also been assumed that $v_0 \ll v'$, p, or $|q|$, which is approximately true at these rates of strain.

If the variations of σ and ε with v' are known, it is an easy matter to determine a, p, and q. The starting velocity v_0' is found from the following expression :

$$\sigma_{UYP} - \sigma_{LYP} = a\log\frac{v_0'}{v'_{crit}}$$

where σ_{UYP} and σ_{LYP} are the extreme values of the stress fluctuations observed in a tensile test, and v'_{crit} is the value of the velocity of the band front when

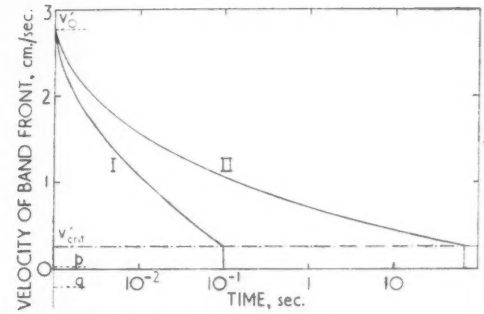

Fig. 6—Theoretical variation of band-front velocity with time

it is suddenly locked. Hence v_0' and B may be determined. Using a value of a derived from measurements at room temperature, v_0' is given as 2·77 cm./sec.

The propagation of a band movement through the material can now be followed. At the peak stress, the band is set free and moves with an initial velocity of about 3 cm./sec. The velocity then decreases according to equation (2), and the plot of v' against t would appear as in Fig. 6, Curve I. In about 0·1 sec. the velocity has fallen to the value at which the band is locked (known, by experiment, to be 0·25 cm./sec.) ; v' then falls abruptly to zero. Values of p and q determined from room-temperature measurements of the parameters involved are also indicated.

The variation in ε is large, since ε increases directly with v', and it is the variation in lateral contraction of the specimen which determines the visibility of the markings.

This analysis also allows for the effect of the testing machine. The rate at which v' falls is governed principally by the time constant in the exponential :

$$\tau = \frac{Aa}{(p-q)V} \text{ sec.}$$

With the hard machine used in the present investigation, the term A, which depends on the elastic constant of the loading spring, is very small ; τ is correspondingly very small, and v' falls rapidly. With a soft machine, however, A can be very large, and in a dead-weight arrangement this term is infinitely large. For a soft machine, therefore, a typical result would be as in Curve II of Fig. 6. In this case, v' falls very slowly, and the time interval before the released band becomes locked again is very long. The band travels a considerable distance, so that the distance between markings on the surface of the specimen is large. Thus, the value of 3 mm. given (p. 333) for the distance between the markings is characteristic of this machine ; the other results, however, are generally true.

Aerodynamic Factors Associated with the Wear of Open-Hearth Furnace Roofs

By J. A. Leys, B.Sc., and E. T. Leigh

SYNOPSIS

The wear of the roof of an oil-fired open-hearth furnace has been investigated by examining the flow conditions existing in a model of the furnace. The causes of the wear are discussed and are concluded to be associated with : (*a*) high-velocity streams, in which combustion may be taking place, impinging on the surface, giving a very high temperature and possibly reducing conditions ; and (*b*) deposition of slag particles from such streams as they turn sharply.

It is shown that the technique of comparing the flow distribution and the deposition of particles from the furnace atmosphere on to the roof of a model of the furnace, with the regions of heaviest wear in the furnace itself, indicates the location and intensity of erosion, so that means of reducing it in the model may be applied to the actual furnace.

The steps suggested to minimize wear are : (i) The maintenance of the burner direction forward of the furnace centre-line, if possible; (ii) the use of a single air port; (iii) the use of a vertical back wall instead of the more usual sloping type.

The most important factor is control of the burner direction.

THE problem of roof wear in open-hearth furnaces is one that has received much attention during the last few years, especially since the increased use of oil firing, which appears to intensify the wear. Research into this problem has, almost without exception, taken the same course, that of correlating the roof wear with the properties of silica bricks. Long series of tests have been carried out and desirable brick properties have been established.[1, 2]

A significant feature of roof wear is that in many cases it is localized. In particular, very severe wear is often observed on the back of the roof above the tap hole. This local effect, which occurs in both oil-fired and gas-fired furnaces but is generally more severe in the former, is frequently observed[3, 4] and is obviously of major significance, but it has not hitherto been possible to relate it to any particular aspects of furnace design. If the cause of the localized wear could be elucidated and steps were taken to remove it, or at least to lessen it, the life of an open-hearth furnace roof would be greatly increased, because just as the roof life usually limits the length of the campaign, so the roof life depends upon the particular regions where the wear is most severe. This research is concerned with an investigation of flow conditions inside the furnace chamber, particularly in the region of heaviest wear.

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Mr. Leys and Mr. Leigh are members of the Aerodynamics Section of the Physics Department of the Research Association.

AIM OF EXPERIMENTS

Recently, model techniques have been increasingly

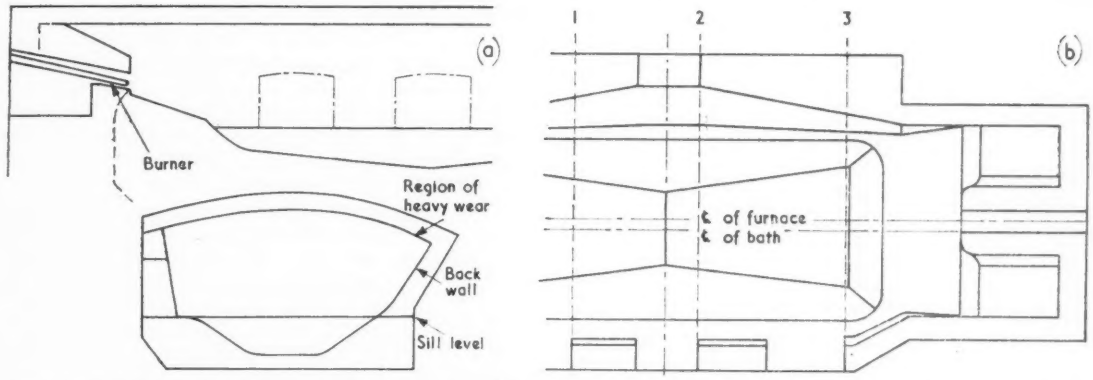


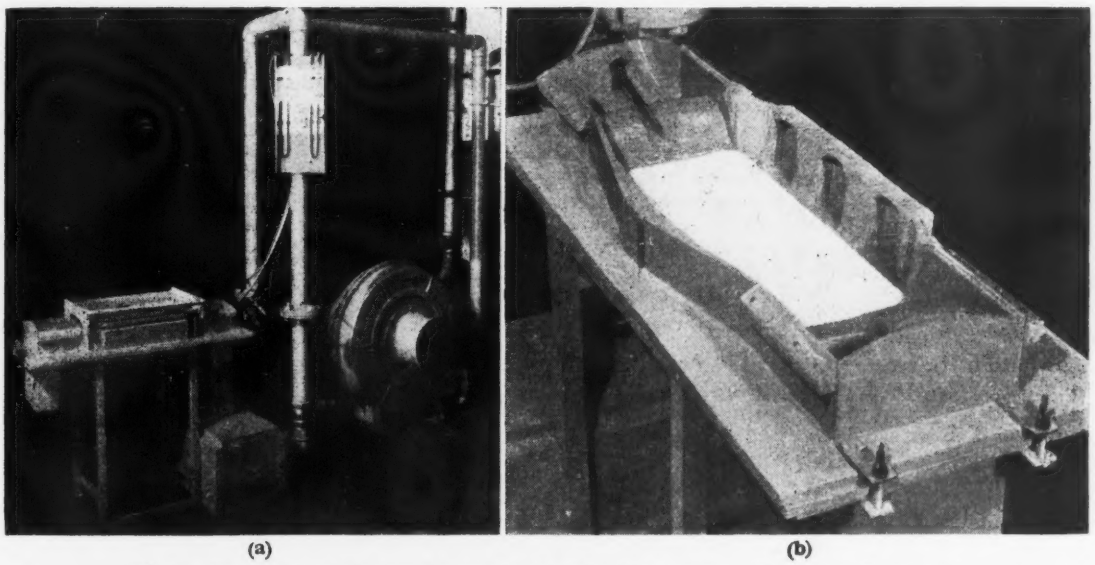
Fig. 1—Details of oil-fired furnace *L* : (*a*) Sections of furnace; (*b*) sections at which velocity readings were taken

used in investigations of flow problems in the open-hearth furnace.[5–8] It was decided to use the air-model technique to study aerodynamic effects associated with roof wear. A particular oil-fired furnace is considered (Fig. 1) in which, as in other similar furnaces, heavy wear has been observed on the back of the roof (*see* Fig. 8) and to a lesser extent on the front of the roof. Figure 8 is a composite picture obtained by photographing the eroded area through the three doors in turn. At the time the picture was taken, the furnace had worked 14 weeks (148 charges) and the roof over the back wall was about to be patched. This deeply gouged section of the roof was observed to be 1–3 in. thick when the main section was about 10 in. thick (but rather less than 10 in. over parts of the front wall).

Consideration of Fig. 8 suggests that aerodynamic effects play a significant part in the mechanism of erosion. It was therefore decided to investigate how the flow distribution of the gases in the furnace depends on certain furnace characteristics, *e.g.*, shape of chamber, orientation of burner, asymmetry of the air flow of the two uptakes, and the shape and position of the uptakes. A cold trial had previously been carried out in the furnace after rebuilding and before firing,[9] and using cold air in both air and burner systems, operating under the necessary similarity criteria. The information gained was valuable but, owing to the time factor and other difficulties, rather limited.

To study these effects, a $\frac{1}{24}$-scale model was built in which the jet direction could be varied, the air uptakes had independent control of flow rate, and the furnace shape could be altered easily. Views of this model are shown in Fig. 2.

It is necessary to study both flow conditions and the deposition of particles from the furnace atmosphere on to the roof, because iron oxide and other fluxes may exist in the furnace chamber in the form of vapour[10] and particles.



(a) (b)

Fig. 2—Views of $\frac{1}{24}$-scale furnace model: (*a*) Complete system; (*b*) with roof removed

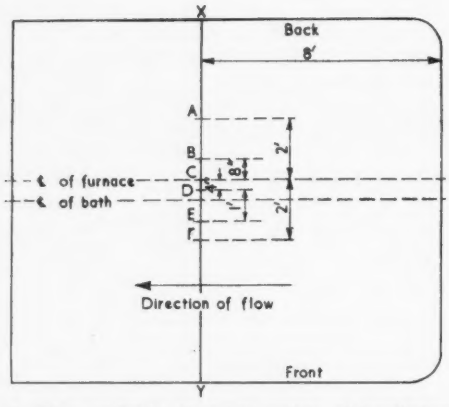


Fig. 3—Plan of bath, showing points of impingement of jet. (Full-scale)

EXPERIMENTAL DETAILS

Techniques

Particle Deposition—The deposition of particles from the furnace atmosphere on to the roof was studied using a modification of a technique originated in this laboratory in 1949. Aluminium particles, approximately spherical and of a particular size (*see* p. 342), were used to simulate the particles present in the furnace atmosphere, which are assumed to be picked up by the fast-moving stream from the bath surface. It was decided, after preliminary experiments, to introduce the particles through the roof *via* a thin glass tube and to release them about $\frac{1}{2}$ in. above bath level (*i.e.*, 1 ft. full-scale). The same series of three entry points directly above points *B*, *D*, and *E* (Fig. 3) was used for all the experiments. For each experiment the roof was made sticky by a thin oil film, and the distribution of the particles on the roof was recorded photographically. The same quantity of particles was used for each experiment, so that comparisons could be made.

Velocity Measurement—Components of velocity, horizontal and parallel to the furnace centre-line, were measured using a Pitot-static tube whose upstream and downstream tappings were 1 cm. apart. By establishing contours of velocity at sections perpendicular to the furnace centre-line, down the length of the furnace chamber, an approximate flow pattern could be constructed. Owing to the limitations of this technique, the results obtained are of a qualitative nature only and are intended to give a general rather than a detailed picture of the flow distribution.

The Furnace Model

A plan of *L* furnace is given in Fig. 1 and the experimental model is shown in Fig. 2. Figure 2*a* shows the separate air supply to the two uptakes ; the jet was supplied from a Roots blower (not shown). Figure 2*b* shows the model with the roof removed. In the original model on which the first flow-distribution experiments were carried out a doghouse was built at each end of the furnace, but these were removed for the other experiments, a doghouse being possible only for a two-uptake system.

Furnace Variables

Geometry of Furnace

Back Wall—In the original design, no part of the back wall was vertical (*see* Fig. 1). At the time of the full-scale cold trial carried out on the furnace,[9] the top 2 ft. 3 in. was vertical. The effect of this modification was considered, and also the effect of a wholly vertical back wall (Fig. 4*a*).

Uptakes and Downtakes—In the original design and at the time of the cold trial, the uptakes were as shown in Fig. 1*b*. Two modifications of this design were considered—the central uptake, and the single uptake occupying the whole furnace end (Fig. 4*b*)—and it was arranged that the total uptake (and downtake) area was the same in each of the three cases.

Orientation of the Burner—It was assumed that in normal practice the oil burner is probably directed along the furnace centre-line to strike the bath as shown in Fig. 1. The effect of jet orientation was determined by varying the point of impingement across the bath (*XY* in Fig. 3), by rotating the burner about a point in the end wall.

Asymmetry in the Air Flow

To determine whether the flow distribution in the furnace might be influenced by an asymmetrical air inflow, the two air uptakes were given independent variable supply. This effect had previously been investigated in a model of a Venturi furnace,[8] and had given a negative result ; with a conventional uptake system the ratio of quantities passing up the two uptakes was 7 : 6, with the excess up the stage side. In the cold trial on *L* furnace, velocity measurements in the uptakes showed approximately equal flows up the two sides. This is thought to be due to the unconventional nature of the regenerator and slag-pocket systems.

Procedure

The flow rates in the model were first calculated from the similarity theory given in the Appendix.

With the normal uptake system and normal back wall, the influence of burner direction on flow distribution was investigated. As a preliminary, flow patterns were established for points of impingement *C*, *A*, and *F* (Fig. 3), by recording velocity readings at sections 1–3 (Fig. 1*b*). Next, a point *D* between the centre-lines of the furnace and bath was considered, and then two points *B* and *E* equidistant from *D*. It was decided to use these three burner

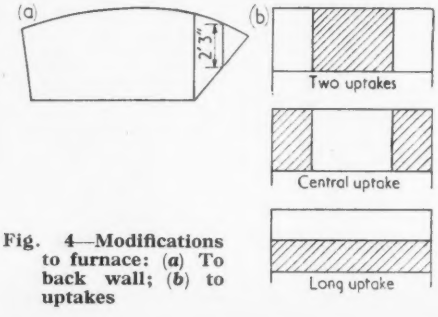


Fig. 4—Modifications to furnace: (*a*) To back wall; (*b*) to uptakes

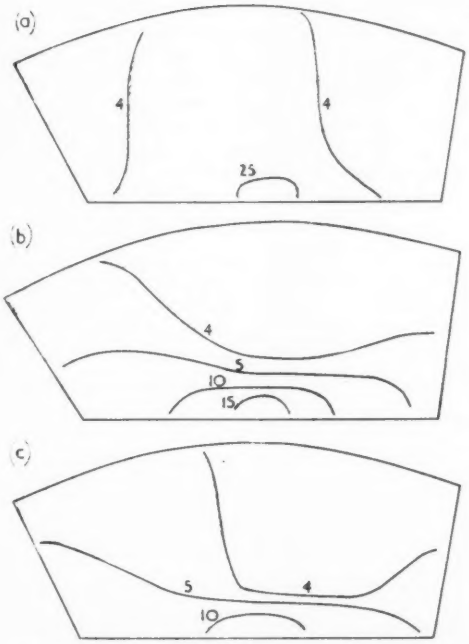


Fig. 5—Velocity distribution in furnace chamber. Burner at *D*, normal uptakes, and normal back wall. (*a*) At section 1; (*b*) at section 2; (*c*) at section 3

directions, because at *D* a nearly symmetrical pattern was given and at *B* and *E* the patterns were reasonably divergent.

With the jet directed at *D*, the effect of ingoing air asymmetry was determined by recording the velocity distributions at section 2 for a 10% excess of air in each uptake in the furnace.

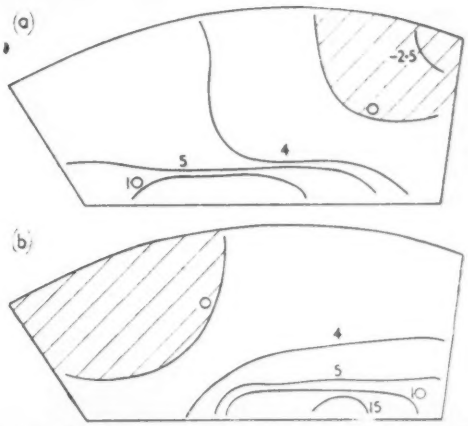


Fig. 6—Velocity distributions at section 2, for two burner directions. Normal uptakes and normal back wall. (*a*) Burner at *B*; (*b*) burner at *E*

With the normal sloping back wall and the jet directed at *D*, the two uptake modifications were investigated. Finally, with the normal uptakes, the back-wall modifications were investigated. For the particle deposition experiments, three jet directions (*B*, *D*, and *E*) were used with the three uptake systems and three back-wall slopes. The deposition of particles on to the roof for every combination of these nine variables gave 27 experiments.

EXPERIMENTAL RESULTS

For convenience, the results of the experiments have been tabulated (Table I). The main features of one of the flow distributions are shown in Fig. 5, for jet direction *D* and normal uptakes and back wall. Figure 6 shows the effect of placing the burner at *B* and *E*. The values of velocity on each contour are arbitrary, taking the burner velocity as 100. Figure 9 is a typical particle deposition photograph, illustrating

Table I

RESULTS OF EXPERIMENTS ON $\frac{1}{24}$-SCALE FURNACE MODEL

Burner Direction	Uptake	Back Wall	Flow Pattern	Particle Deposition
B, *D*, *E*	Normal	Normal	Figs. 5 and 6	Fig. 9
A, *C*, *F*	Normal	Normal	With the burner at *C* there is a considerable amount of back flow, and the pattern is similar to that for the burner at *B*. At the two extremes *A* and *F*, very asymmetrical flow patterns are given	
D	Normal	Normal	Effect of asymmetrical air inflow: 10% excess on either side can be tolerated without much alteration of the flow pattern. A pit-side excess introduces some return flow in front of the chamber	
B, *D*, *E*	Normal	Two modifications	Changing the slope of the back wall tends to shift slower-moving parts of the flow towards the front wall. Faster-moving streams are relatively unaffected	Less deposition as the slope of the back wall increases. Much smaller effect than changing the burner direction
B, *D*, *E*	Two modifications	Normal	With the central uptake the pattern is flatter, but with the long uptake the pattern is similar to the normal	A general decrease in deposition results from the use of long and central uptakes. The long uptake with a vertical back wall gives the least deposition. These modifications, however, have smaller effects than changing the burner direction

the effect of changing the burner direction (indicated approximately by an arrow at the side of each picture).

DISCUSSION OF RESULTS

The flow pattern (Fig. 5) for the burner at *D* is characterized by the absence of return flow, the jet spreading out across the bath and up the back and front walls. This sweeping effect up the back wall appears to be much more pronounced than that up the front wall, and has been confirmed on the model by visual observations, using a smoke filament as a tracer (*see* Fig. 7). Also, high-speed ciné pictures

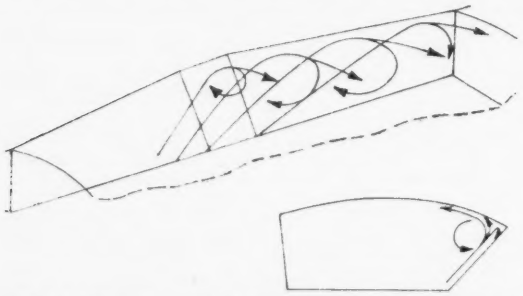


Fig. 7—Flow in region of roof over the back wall

taken through the end wall of the actual furnace while in operation showed precisely this effect. The absence of return flow in Fig. 5 does not mean that no such flow exists ; there will be local back-flowing streams, but the mean flow is in a forward direction. Figure 6, for the jet directed at *B* and *E*, shows that the flow pattern can be ' set ' to an asymmetrical form, either to the front or back wall, by a comparatively small movement of the burner. In both cases there is a fairly large region of return flow. From Fig. 9 it can be seen that change of burner direction produces large changes in the deposition pattern, in the same way that it produces large changes in the flow pattern. As might be expected, changing the burner direction away from the back wall decreases the deposition over the back of the roof. The change of direction from *B* to *D* produces far less change in the deposition than the change from *D* to *E* ; that is, the biggest effect is obtained by directing the burner slightly into the front half of the chamber. For the direction *C* along the furnace centre-line (which is possibly a normal operating direction), the flow pattern is very similar to that at *B*, demonstrating that a small deviation of the burner towards the back wall may produce a large change in flow pattern.

The experiments on an asymmetrical air inflow showed that a 10% excess on either side can be tolerated without having a large effect on the flow pattern. By decreasing the slope of the back wall to the vertical, the shape of the furnace chamber is made less asymmetrical, and (as might be expected) the sweeping up the back wall is reduced, as is the deposition.

The effect of introducing the combustion air into the furnace at the centre of the end is to flatten the flow pattern, *i.e.*, to depress the contours ; less deposition results. When air is introduced through corner uptakes, it apparently flows to the centre of the roof and then moves down on to the jet, promoting the upward swirl of the jet at the sides of the furnace. Air introduced at the centre will spread outwards over the roof and will tend to counteract this swirling motion. The experiments thus show that large changes in flow pattern can be produced by altering the burner direction, and smaller changes by altering the slope of the back wall and the type of uptake.

CAUSES OF INCREASED WEAR

It has been observed that iron oxide and other fluxes are absorbed all over the roof in least-worn as well as most-worn parts,[1] and that the wear is very severe in the part of the roof over the back wall. Also, the roof is run at a temperature very near the melting point of silica, and will therefore probably have an almost liquid surface layer.

The possible causes of accelerated wear are :

(i) Direct abrasion. If there are solid particles in the furnace atmosphere, picked up from the bath, the softness of the roof surface would allow direct abrasion. The foregoing experiments, and observations by smoke filaments on the model and by high-speed ciné pictures on the furnace, show that the flow is of the correct nature to allow this.

(ii) Overheating by radiation. It has been suggested[4] that in a furnace with a sloping back wall the region of the roof over the tap hole is over a refractory which is hotter than the comparatively cool bath.

(iii) Overheating by convective heat transfer. The stream of gas passing over the eroded area is probably hotter and moving faster than the gas over any other part of the furnace roof. It might be supposed that this effect could be examined by direct temperature measurement, but this has proved difficult. The relative temperatures of back and crown of the roof appear to be different at different stages of the charge.[11] Tests are continuing on this subject.[12]

(iv) Deposition of particles on the roof under certain atmospheric conditions might give rise to a chemical action, lowering the melting point of the silica.

It has been found that, under oxidizing conditions, absorption of iron oxide has little effect on the refractoriness of silica brick,[1] but under reducing conditions the refractoriness is lowered severely.[13–16] Iron oxide is probably present in the furnace atmosphere in solid, liquid, and vapour[10] forms ; as vapour it may condense out all over the roof and be absorbed, but the main parts of the roof are washed either by back-flowing waste gases or by ingoing air, and thus the absorption takes place under oxidizing conditions, and does little harm. Only over the back wall, and to a lesser extent the front wall, is the roof always washed by a forward-moving gas stream, in which combustion is probably still taking place, so that the atmosphere may be spasmodically reducing. Also, any deposition of solid or liquid iron oxide particles will take place in these regions. Thus the processes taking place in the regions of most wear are : (i) The roof is overheated by forward-moving gases in which combustion may be taking place, and (ii) solid and liquid particles are deposited ; these two may be the most significant effects operating. There may also be some abrasion by solid particles, but the surface at such places would probably drip to the bath or be carried away by the gas stream ; the pattern on the eroded roof (Fig. 8) supports this assumption. Radiation effects are unlikely to be important, since this

Fig. 8—Erosion of roof of *L* furnace after 14 weeks

[*Leys and Leigh*
[*To face p.* 340

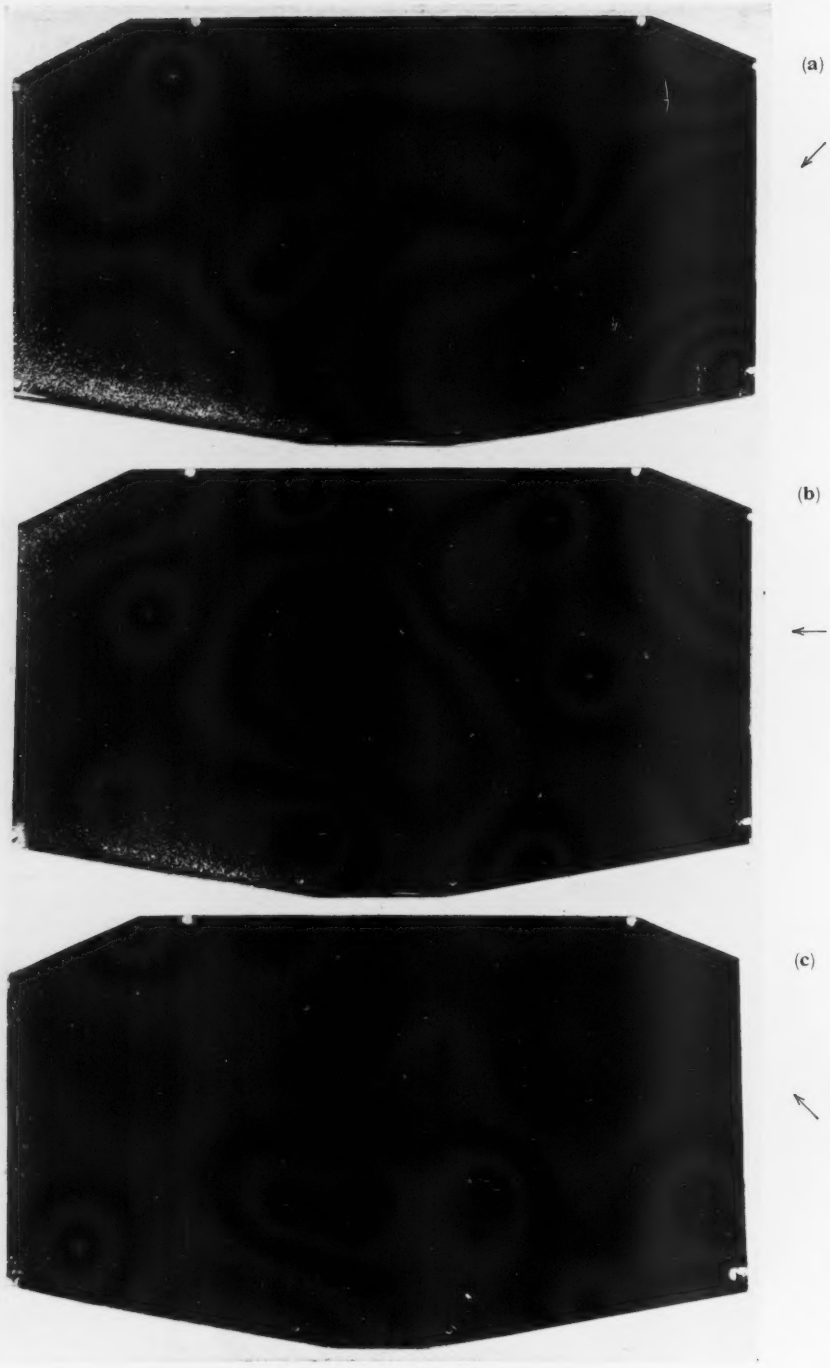


Fig. 9—Particle deposition for various directions of burner. Two uptakes and sloping back wall. (*a*) Burner at *B*, pointing downwards at approx. 20° to the horizontal; (*b*) burner at *D*, horizontal; (*c*) burner at *E*, pointing upwards at approx. 25° to the horizontal

form of localized wear has been observed on furnaces with vertical back walls.[4]

CONCLUSIONS

(1) These experiments on the model have shown that the region of heaviest erosion on the roof is associated with a high-velocity stream of gas which impinges on the surface and turns sharply, and in which combustion may still be taking place; it is also associated with the deposition of solid and liquid particles of iron oxide picked up by the jet. The eroded area is overheated by the fast-moving stream from the burner, and the deposition of iron oxide particles under these conditions may cause chemical action and a lowering of the melting point. This motion of the gas stream has been observed in a cold trial on the furnace,[9] and by high-speed ciné pictures taken on the furnace when working.

(2) Since the model technique indicates the location of the regions of heaviest wear, steps taken on the model to suppress the two effects mentioned in conclusion (1) may also be applied to the actual furnace.

(3) It is suggested that localized erosion may be diminished by:

(i) Directing the burner, when possible, forward of the furnace centre-line
(ii) Using a single air port, either centrally placed or extending across the whole furnace end
(iii) Using a vertical back wall instead of the more usual sloping one.

Control of the burner direction is by far the most important of the three effects.

Since the burner direction is critical, valuable information would be obtained by carrying out further cold experiments on the actual furnace, recording the flow distributions for varying burner direction.

The logical and necessary extension of model work will be the determination of the flow distribution in a working furnace. Some of the problems to be overcome are: the maintenance of the furnace under steady conditions for sufficient time for such a trial to be carried out; the development of an efficient instrument for measuring gas velocities at steelmaking temperatures; and the accurate manipulation of such an instrument in a furnace chamber.

The main value of the present work has been the development of a technique for studying the wear of furnace refractories in a model. It is recognized that these tentative conclusions concerning a particular furnace may not be generally applicable, and it is intended to carry out further experiments on furnaces of different design.

APPENDIX

Theoretical Considerations

Flow Distribution

To consider the similarity between an oil-fired furnace and an air model, it is necessary to determine to what extent a single-fluid model can simulate a two-fluid system in which combustion takes place.

In a furnace, combustion takes place as the jet entrains air, producing changes of temperature. In the present and similar furnaces the combustion air is preheated to about 1200° C., and it is suggested that the resulting distortion of the flow pattern due to the temperature changes will not be great. To calculate the flow rates in the model, the flame and its surroundings are assumed to have the properties of air at 1500° C. This assumption will give a false picture of the flow pattern very near the burner, but a better picture as mixing progresses. Temperature deviation from this assumed value will not be greater than $\pm$ 300° C., and will generally be much less. It is realized that if, for example, a detailed picture of the mixing of the two streams were required, more careful consideration would be necessary.

Similarity may be obtained by ensuring Reynolds similarity in the combustion air flows, and also in the burner flows. This is a simple matter for the air, but the problem is more difficult in the burner, since the fuel changes state as it leaves it. For the jet flow it is more convenient to consider the momentum in the burner, since this has been estimated for a steelworks burner and has also been measured by determining the reaction at the burner itself while in operation.

For flow similarity:

$$(R_J)_{furnace} = (R_J)_{model}$$
$$(R_A)_{furnace} = (R_A)_{model}$$

where the suffixes J and A refer to jet and air, respectively.

$$\therefore \quad \left(\frac{R_J}{R_A}\right)_{furnace} = \left(\frac{R_J}{R_A}\right)_{model} \qquad \text{.....(1)}$$

If the furnace can be assumed to behave as a single-fluid system (air at 1500° C.), equation (1) reduces to:

$$\frac{L\sqrt{\Sigma G}}{M_e} = \frac{\sqrt{\sigma g}}{m_e} \qquad \text{.....(2)}$$

where:

L = reciprocal of the scale ratio of the model
Σ, σ = densities of furnace and model fluids, respectively
G, g = jet momenta in furnace and model, respectively
M_e, m_e = mass flow-rates of the combustion air in the furnace and model, respectively.

It was on the estimates of burner momentum and air flow rates in the furnace that the flow similarity was based.

Owing to air supply considerations it was necessary to run the model at reduced Reynolds numbers, but equation (1), and hence equation (2), was still satisfied. This procedure is permissible in a model of this nature, provided that the flow is fully turbulent. The whole question of using a single-fluid model to simulate such a complex system as an oil-fired open-hearth furnace has been discussed frequently in the past,[6–8] and measurements on actual furnaces, *e.g.*, of burner momentum, are providing the answer.

Particle Deposition

In this theory, the motion of the particles relative to the gases in the furnace is assumed to follow Stokes' Law. This law applies precisely for Reynolds numbers up to unity, and is not seriously in error for values up to about 10. In any case, the actual relative velocities are not known and are difficult to calculate.

It is also assumed, as in the previous section, that the furnace gases have the properties of air at 1500° C.

Let

V = velocity of the particle
U = velocity of the gas
g = gravitational acceleration
η = viscosity of the gases
η_0 = viscosity of air at room temperature
m = mass of particle
u_0 = free rate of fall of particle in air at room temperature.

The velocity of the particle relative to the gas is $U - V$, and the viscous force exerted on the particle is given by :

$$\frac{U - V}{u_0} \cdot \frac{\eta}{\eta_0} \cdot mg$$

Thus, the equation of motion of the particle is :

$$m\frac{dV}{dt} = mg + mg \cdot \frac{U - V}{u_0} \cdot \frac{\eta}{\eta_0}$$

$$i.e., \quad \frac{dV}{dt} = g\left\{1 + \frac{\eta}{\eta_0} \cdot \frac{U - V}{u_0}\right\}$$

For a particular direction s :

$$\frac{dV}{dt} = V_s\frac{dV}{ds} = g\left\{1 + \frac{\eta}{\eta_0} \cdot \frac{U - V}{u_0}\right\} \quad \text{.....(3)}$$

Let the velocities and lengths in equation (3) be referred to velocities and lengths characteristic of the flow system ; *i.e.*, let :

$$V' = \frac{V}{V_0}, \quad U' = \frac{U}{V_0}$$

$$V_s' = \frac{V_s}{V_0}, \quad ds' = \frac{ds}{D}.$$

Then from equation (3) :

$$V_s'\frac{dV'}{ds'} = \frac{gD}{V_0^2}\left\{1 + \frac{\eta}{\eta_0} \cdot \frac{V_0}{u_0}(U' - V')\right\}$$

$$i.e., \quad V_s'\frac{dV'}{ds'} = F\left\{1 + H(U' - V')\right\} \quad \text{.....(4)}$$

where $F = \dfrac{gD}{V_0^2}$ and $H = \dfrac{\eta V_0}{\eta_0 u_0}$.

In any other flow system, if the boundary conditions are the same, equation (4) will have the same solution for the same values of F and H. Thus there are two new criteria to be fulfilled for flow similarity in the model ; F is, in fact, a Froude number. It may be expressed in terms of the Reynolds number, and may be made the same in model and furnace by ensuring that :

$$\frac{R_{model}}{R_{furnace}} = \frac{1}{5 \cdot 9}.$$

The model must thus be run at reduced but specific Reynolds numbers. It is suggested that a reduction of this order, although greater than the reduction for the velocity measurement experiments, is equally permissible, as the flow is still highly turbulent.

Consider now the coefficient H, where $H = \dfrac{\eta}{\eta_0} \cdot \dfrac{V_0}{u_0}$.

The term V_0 is fixed by the Froude criterion, and η, being a physical property of the gases, is also fixed, so that to make H the same in model and furnace the free rate of fall of the particles to be used in the model must be related to the free rate of fall of the furnace particles in air at room temperature (u_0).

A reasonable order of size for particles in the furnace is from 1 mm. downwards and with a density of 4 g./c.c. Their shape is unknown, but for determining their free rate of fall it is not unreasonable to assume them to be spheres.

Applying Stokes' Law in this way, the relationship between the radius (a_F) of a particle in the furnace and the radius (a_M) and density (ρ_M) of the corresponding particle in the model, is shown to be :

$$\left(\frac{a_M}{a_F}\right)^2 \cdot \rho_M = \frac{1}{4} \quad \text{.....(5)}$$

Aluminium particles having approximately spherical shape and density 2·7 g./c.c. were used in the model experiments, and from equation (5) it was found necessary to use particle sizes of 0·3 mm. and smaller.

Acknowledgments

The authors are indebted to Mr. M. W. Thring, Mr. M. P. Newby, and Mr. R. D. Collins, for their helpful advice during these experiments ; to Mr. C. H. Bacon, for permission to reproduce Fig. 8 ; and to Mr. Bacon and Dr. A. H. Leckie for their helpful comments on the paper.

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Determination of Vanadium in Ferro-Vanadium

By the Methods of Analysis Committee

SYNOPSIS

As part of an investigation on the determination of vanadium in ferrous materials the analysis of ferro-vanadium has been studied. Various techniques for the formation of pentavalent vanadium in sulphuric acid solution have been compared and the method finally recommended is described. This includes oxidation with permanganate, the excess being reduced by sodium nitrite/sulphamic acid treatment, and titration of the pentavalent vanadium with standard ferrous ammonium sulphate solution. Exact balance to the change-point of barium diphenylamine sulphonate indicator is achieved with standard potassium dichromate.

SUITABLE methods for the determination of vanadium have been considered by the Methods of Analysis Committee under three main headings:

(*a*) Carbon and low alloy steels and irons
(*b*) Highly alloyed steels with particular reference to high-speed tool steel
(*c*) Ferro-vanadium alloys.

A report of an investigation[1] conducted by the Pig Iron, Carbon and Low Alloy Steels Analysis Sub-Committee covers group (*a*). Work on group (*b*) will be commenced following the recommendations put forward by the Pig Iron, Carbon and Low Alloy Steels Analysis Sub-Committee. Group (*c*) forms the subject of the present report.

The work has been carried out by the Highly Alloyed Steels and Ferro-Alloys Analysis Sub-Committee, constituted as follows:

Mr. B. BAGSHAWE (*Chairman*)	Brown-Firth Research Laboratories
Dr. J. CAMERON*	The Clyde Alloy Steel Co., Ltd.
Mr. E. DYKE	Brown-Firth Research Laboratories
Mr. W. T. ELWELL	I.C.I. Ltd., Billingham Division
Mr. L. E. GARDNER	Edgar Allen and Co., Ltd.
Mr. C. L. GRAYSON	English Steel Corporation Ltd.
Mr. E. W. HARPHAM	B.S.A. Group Research Centre
Mr. S. HARRISON	Kayser, Ellison and Co., Ltd.
Mr. J. D. HILL	Bragg Laboratory, N.O.I.D.
Mr. R. T. POSTLETHWAITE	Samuel Fox and Co., Ltd.
Mr. L. N. TAYLOR	Samuel Osborn and Co., Ltd.
Mr. J. L. WEST	Hadfields Ltd.

* Until 31st March, 1950.

The method of analysis finally recommended by the Sub-Committee is described in the Appendix to this report, and it has been submitted to the British Standards Institution for approval.

DETAILS OF INVESTIGATION

Discussion and experience showed that gravimetric procedures did not warrant consideration and that a volumetric method based on the measurement of the $V_2O_5 \rightleftharpoons V_2O_4$ transformation, and which did not require the separation of any elements occurring in ferro-vanadium, afforded the most suitable basis for study. The $V_2O_5 \rightleftharpoons V_2O_4$ transformation is capable of measurement in either direction, *i.e.*, by titration of the pentavalent vanadium by a standard reducing agent such as ferrous sulphate, or by titration with a standard oxidizing agent such as potassium permanganate after a suitable reduction to the tetravalent state. The latter reduction may be effected with several reagents, *e.g.*, sulphur dioxide, hydrogen sulphide, or ferrous sulphate, but of these only ferrous sulphate is directly applicable to a ferro-alloy solution, as sulphur dioxide and hydrogen sulphide both reduce ferric salts and the separation and removal of iron would introduce an undesirable complication.

The choice had to be made, therefore, either to use ferrous sulphate as a titrant for the oxidized vanadium solution after reduction of any excess of oxidant, or to reduce the vanadium solution and, after oxidizing the excess of reductant, to titrate the reduced vanadium solution with standard potassium permanganate. The latter form is often used in conjunction with chromium determinations in steel, but evaluation by permanganate titration has the disadvantage that the reaction is slow in cold solution, whilst a hot solution is inadmissible if persulphate has been used to destroy ferrous salt or if chromium is present. Furthermore, a slow titration is less convenient for ferro-vanadium because of the larger titre compared with steel. The test procedures have therefore all utilized ferrous sulphate as titrant after suitable conversion of the vanadium to the pentavalent condition.

Preliminary trials were made using test conditions in which the vanadium was obtained in the pentavalent form by a regulated cold oxidation with permanganate applied to two equal aliquots from the same solution. This solution was obtained by dissolving 2·5 g. of sample in a mixture of 100 ml. of water, 25 ml. of sulphuric acid (sp. gr. 1·84), and 25 ml. of nitric acid (sp. gr. 1·42). After fuming, the solution was diluted to 500 ml. and 100-ml. aliquots taken. An addition of phosphoric–sulphuric acid was made immediately before titration with $N/10$ ferrous ammonium sulphate solution; barium diphenylamine sulphonate was used as an indicator.

Small additions of permanganate were made alternately to these aliquots, in an attempt to achieve complete oxidation with a minimum excess of the reagent. This proved to be tedious, although the results obtained confirmed the non-interference of chromium. These results for sample MGS/114 are shown in Table I. The test sample of ferro-vanadium

Paper MG/D/300/51 of the Methods of Analysis Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association, received 1st January, 1952.

was known to contain chromium (*circa* 1%) and further additions were made, up to the equivalent of 7% chromium, without causing interference.

Comparison of Methods

Control of permanganate oxidation in the foregoing procedure was tedious, although the results were quite accurate when operating details were carefully defined. Experiments were devised in which the $V_2O_4 \rightleftharpoons V_2O_5$ oxidation was made with a small, but definite, excess of permanganate. This permitted a more rapid conversion of V_2O_5 and eliminated the need for a matched pair of aliquots. Reduction of surplus permanganate, after completing the cold oxidation, was made with sodium nitrite, hydrochloric acid, and sodium azide respectively.

Table I

RESULTS BY FIRST TRIAL METHOD—EFFECT OF CHROMIUM*

Operator	Vanadium, %	Chromium Added, %
A	53·9	Nil
	53·9	Nil
	53·85	Nil
	53·9	3
	53·95	3
	54·0	3
B	53·5	Nil
	53·5	Nil
	53·55	1·04
	53·5	1·04
	53·6	2·08
C	53·85	Nil
	53·9	Nil
	54·05	Nil
D	54·0	Nil
	54·1	Nil
	54·1	Nil
	54·25	Nil
E	54·3	Nil
	54·5	Nil
	54·6	Nil
	54·4	Nil
F	53·85	Up to 7%
	53·9	Up to 7%
	53·9	Up to 7%
G	54·2	Nil
	54·0	Nil
	53·9	Nil
H	53·75	Nil
	53·85	Nil
	53·75	Nil
	53·95	Nil

* This sample contains 1·07% chromium

Table II shows a comparison of results by four modifications of the original procedure. The chief differences were :

(*a*) hydrochloric acid reduction of excess permanganate, final titre obtained by back titration with *N*/10 potassium dichromate solution

(*b*) nitrite reduction of excess permanganate, hydrofluoric acid added instead of phosphoric acid before titration, direct titration with *N*/10 ferrous ammonium sulphate solution

Table II

EFFECT OF DIFFERENT METHODS OF REDUCTION OF EXCESS PERMANGANATE

Analyst	Vanadium, %			
	Hydrochloric Acid (*a*)	Nitrite (*b*)	Nitrite (*c*)	Azide (*d*)
A	53·9	53·85	53·85	
	53·95	53·95	53·65	
B	54·05	54·15	53·6	
	53·95	54·0	53·65	
		54·1		
C	54·1	53·5	53·4	53·3
	54·3	53·5	53·45	53·55
	53·85	53·6	53·45	53·4
	54·2	53·6	53·45	53·55
	53·95	53·5		
	54·0	53·5		
		53·6		
		53·6		
		53·6		
		53·7		
D	53·7	53·6	53·6	
	53·65	53·7	53·6	
	53·7	53·7	53·7	
E	53·45	53·5	53·65	
	53·8	53·5	53·5	
	53·4	53·55	53·6	
	53·7	53·55	53·5	
	53·55		53·7	
F	54·0	54·2		
	54·0	54·4		
	53·8	53·8		
G	53·9	53·8		
	53·8	53·8		
	53·8	53·75		
H	53·95	54·0	53·9	53·9
	53·9	54·0	54·0	54·0
I	53·2	52·6		53·3
	52·4	52·6		53·4

(*c*) As (*b*) using phosphoric acid and back titration

(*d*) As (*a*) using sodium azide for hydrochloric acid.

The results are similar by the four methods. The use of hydrochloric acid was, however, discontinued as it was shown that a trace of permanganate remains until the solution attains a temperature of 80° C. At this temperature chromium oxidation occurs, and in a particular experiment, in the presence of 10 mg. of chromium, 1·7 mg. were oxidized before the hydrochloric acid became operative in reducing the remaining permanganate.

Using various reagents to reduce excess permanganate after the preliminary oxidation, the results shown in Table III were obtained on solutions containing known amounts of ammonium metavanadate. For comparison, similar solutions were reduced with sulphurous acid and titrated at 70° C. with standard permanganate, after removing excess sulphur dioxide by boiling. In one case hydrogen sulphide was used instead of sulphur dioxide.

The ammonium vanadate solutions were prepared individually by members and were not, therefore, of identical concentration. The results are acceptable although they show a tendency to be slightly low compared with sulphurous acid reduction.

The adoption of nitrite as the preferred reducing agent for the excess permanganate led to a comparison being made of urea and sulphamic acid[2] as reagents for the destruction of excess nitrite. Tests were made in conjunction with final trials of the recommended method on two ferro-alloy samples and whilst the results (Table IV) signify no real advantage for either reagent, the Sub-Committee recommend sulphamic acid in view of its more rapid action.

CONCLUSIONS

The method which the Sub-Committee recommend for adoption is described in the Appendix. The conclusions and observations of the Sub-Committee embodied in these draft conditions are summarized as follows :

(1) Preference is for direct operation on a suitable sample weight, *e.g.*, 0·5 g., rather than fractionation from an initial solution of a larger weight. There is no evidence that heterogeneity should be allowed to determine the choice of sample weight. The reproducibility obtainable is $\pm 0{\cdot}25\%$ vanadium on commercial grades of the alloy.

(2) It is not normally practicable to use sample material finer than 40 mesh, but complete solubility is readily obtained under the solution conditions specified. The insoluble siliceous residue contains minor quantities of oxidized vanadium compounds. Since the steelmaking value of the alloy is related to its metallic content only, a determination that does not involve a treatment of the non-metallic residue may be of more value than a determination of total vanadium. The recovery of non-metallic vanadium from the slaggy residue is, therefore, made an optional feature and is covered by a note.

(3) Permanganate oxidation of vanadium in cold solution is a relatively slow reaction and to ensure complete oxidation to the pentavalent condition a small but definite excess of permanganate is necessary. This requirement is stressed because a pink tinge may be obtained which persists for some time before oxidation of vanadium is complete. An additional 0·5 ml. of permanganate is, therefore, specified after a pink tinge persisting for a full minute is obtained.

(4) The titration reaction is improved by the presence of phosphates or fluorides. Both have been used during the investigation and there is little to choose between them. Hydrofluoric acid was finally adopted, as it was considered that its use held a slight advantage in end-point sensitivity.

(5) At various stages of the work, opinion has been divided between titration with the ferrous sulphate to the reduced change-point of the barium diphenylamine indicator and addition of excess ferrous sulphate

Table III

COMPARISON OF REDUCTION BY SULPHUROUS ACID WITH OXIDATION BY $KMnO_4$

Analyst	Vanadium, g.				
	Sulphurous Acid Reduction and Permanganate Titration at 70° C.	$KMnO_4$ Oxidation and Reduction of Excess by			
		Hydrochloric Acid (*a*)	Nitrite (*b*)	Nitrite (*c*)	Azide (*d*)
A	0·2149, 0·2149 0·2139, 0·2139	0·2139, 0·2136 0·2144	0·2135, 0·2135 0·2133		0·2134, 0·2134 0·2139, 0·2129
B	0·2151			0·2142, 0·2142 0·2142	
C	0·2155 0·2155	0·2142 0·2145			
D	0·2178 0·2178	0·2177	0·2177	0·2178 0·2178	0·2180
E	0·2512 0·2514*			0·2502, 0·2504 0·2509, 0·2502	

* Reduced with hydrogen sulphide instead of sulphurous acid

Table IV

COMPARISON OF UREA AND SULPHAMIC ACID FOR DESTRUCTION OF EXCESS NITRATE

Analyst	Vanadium, %			
	Sample MGS/114		Sample MGS/136	
	Urea	Sulphamic Acid	Urea	Sulphamic Acid
A	53·6 53·7	53·9 53·9	38·1 38·1 38·1	38·1 38·2 38·15
B	53·6 53·65 53·65	53·6 53·6 53·55	38·0 38·0 38·0	38·05 38·05 38·0
C	53·75 53·7	53·75 53·65	37·9 38·0	37·95 38·0
D	53·6 53·5	53·4 53·4	37·8 37·9 37·9	37·8
E	53·75 53·9	53·8 53·9	38·2 38·15	38·2 38·1
F			37·95 37·95	37·95 37·9
G	53·7 53·75 53·8	53·8 53·85 53·85	37·9 37·95 37·85 37·85 37·95 37·9	37·95 38·0 38·0 38·0 38·05 38·05
H			38·0 38·15	38·0 38·15
I		53·7 53·75	37·9 37·9	38·0 37·95
Mean Deviation ±	0·2 0·2	0·2 0·3	0·2 0·2	0·2 0·2
Average	53·7	53·7	38·0	38·0
Range	0·4	0·5	0·4	0·4

followed by back titration with standard dichromate, to the oxidized change-point of barium diphenylamine sulphonate. A slight preference was shown for the latter and this was adopted.

(6) High carbon or high silicon alloys may require some modification in the method of decomposition, otherwise the procedure should be applicable to any type of ferro-vanadium alloy encountered in steelworks practice.

References

1. B.I.S.R.A. Paper MG/DB/279/51.
2. W. B. Shaw: *Metallurgia*, 1950, vol. 41, pp. 234–236.

APPENDIX

Recommended Method for the Determination of Vanadium in Ferro-Vanadium

Solutions Required

Sulphuric acid (1 : 4)
Potassium permanganate (0·5%)
Sodium nitrite (0·5%)
Sulphamic acid (10%).

Barium Diphenylamine Sulphonate Indicator (0·2%)—Dissolve 0·2 g. of barium diphenylamine sulphonate in 80 ml. of hot water, cool, and dilute to 100 ml.

Ferrous Ammonium Sulphate (N/10 *approx.*)—Dissolve 40 g. of ferrous ammonium sulphate ($FeSO_4.(NH_4)_2SO_4.6H_2O$) in a mixture of 500 ml. of water and 20 ml. of sulphuric acid (sp. gr. 1·84), cool, and dilute to 1 litre.

Potassium Dichromate (N/10)—Dissolve 4·9035 g. of potassium dichromate (previously crushed, dried at 180° C., and cooled in a desiccator) in water, dilute to 1 l., and shake well.

Procedure

Digest 0·5 g. of the 40-mesh sample (Note 1) in 60 ml. of sulphuric acid (1 : 4) and 5 ml. of nitric acid (sp. gr. 1·42) until complete decomposition is obtained (Note 2), evaporate the solution until sulphur trioxide fumes appear, cool, dilute to 200 ml., and boil to dissolve soluble salts (Note 3). Cool the solution to room temperature, dilute to 300 ml., and add 3 ml. of ferrous ammonium sulphate solution (*N*/10 approx.) (Note 4). To the cold solution add potassium permanganate solution (0·5%) until one drop gives a pink colour that persists for 1 min., add 0·5 ml. in excess, and allow to stand for a further 1 min.

Reduce the excess of permanganate with dropwise additions of sodium nitrite solution (0·5%) until the pink colour is discharged, adding not more than 5 drops in excess; add 5 ml. of sulphamic acid (10%) and mix the solution thoroughly.

Add 1 ml. of hydrofluoric acid and 0·5 ml. of barium diphenylamine sulphonate indicator. Allow the purple colour of the indicator to develop and titrate the solution with ferrous ammonium sulphate solution (*N*/10 approx.) until the colour changes to green. Add 3–4 ml. excess of ferrous ammonium sulphate solution (*N*/10 approx.) and back titrate with potassium dichromate solution (*N*/10) to a deep violet colour.

Standardization

Dilute 60 ml. of sulphuric acid (1 : 4) to 300 ml. Add 1 ml. of hydrofluoric acid and 0·5 ml. of barium diphenylamine sulphonate indicator. Add 5 drops of ferrous ammonium sulphate solution (*N*/10 approx.), then potassium dichromate solution (*N*/10) dropwise until a deep violet colour is just obtained. Add 40 ml. of ferrous ammonium sulphate solution (*N*/10 approx.) and titrate with potassium dichromate solution (*N*/10) to a deep violet end-point, recording the volume of potassium dichromate solution required to

titrate the 40 ml. of ferrous ammonium sulphate solution.

Calculation

1 ml. of potassium dichromate ($N/10$)
$= 0{\cdot}005095$ g. of vanadium

Therefore vanadium $\% = (A-B) \times 0{\cdot}005095 \times 200$
$= 1{\cdot}019\ (A-B)$.

Where A ml. = volume of ferrous ammonium sulphate corrected to $N/10$

B ml. = volume of potassium dichromate ($N/10$) actually used in the assay titration.

NOTES

(1) Where heterogeneity of the alloy is suspected a larger weight may be taken and the solution subsequently fractionated. Replicate results should lie within $\pm 0{\cdot}25\%$ of the true figure.

(2) If separation of silicic acid appears to be retarding the solution process, a few drops of hydrofluoric acid may be added with advantage.

(3) To recover any vanadium that may be present, filter the solution through a pulp pad, wash with hot dilute sulphuric acid (1 : 99) and finally wash once or twice with water. Ignite the siliceous residue and pad in a platinum dish at a temperature not exceeding 650° C., cool, add 7 drops of sulphuric acid (1 : 4) and 30 drops of hydrofluoric acid. Evaporate until the free acids are expelled and ignite at a low temperature. Fuse the residue with a small quantity of potassium bisulphate and extract the fusion products in 50 ml. of dilute sulphuric acid (1 : 99). This extract may now be combined with the main solution for a determination of total vanadium or reserved for separate examination if required.

(4) To ensure that any chromium that may be present is in the trivalent condition.

Pressure Distribution Between Stock and Rolls in Hot and Cold Flat Rolling

By C. L. Smith, M.A., Ph.D., F. H. Scott, Ph.D., B.Met., and W. Sylwestrowicz, Dipl. Ing.

SYNOPSIS

A method of measuring the pressure distribution over the area of contact between the roll and rolled stock is described. In this method a photoelastic dynamometer, inside the lower roll, measures the normal force exerted on a small radial pin inset into the roll, the surface of the pin being flush with the roll surface. Devices for applying back tension to the rolled strip, and for measuring the back tension and the total force separating the rolls, are also described. Results are given for the cold rolling of annealed copper strip, 2 mm. thick × 40 mm. wide, for reductions from 5% to 50%, and for similar hot-rolled copper strips with reductions of 18%, 26%, and 36%. These results are compared with results calculated by Orowan's method. The values of the yield stress of copper, measured over the area of contact, are discussed, as is the method of measuring the coefficient of friction between the roll and rolled stock.

Introduction

ALTHOUGH it has long been realized that a knowledge of the distribution of pressure over the area of contact between the mill rolls and the rolled stock is important, the only measurements made so far are those of Siebel and Lueg, in 1933.[1] (An earlier but unsuccessful attempt was made by Huber.[2]) Except for Siebel and Lueg's investigation, all experimental work on roll pressure has been confined to the measurement of the total force separating the rolls, *i.e.*, the integral of the vertical pressure over the area of contact. The reasons for undertaking the present work will therefore be briefly reviewed.

In sheet or strip rolling, the roll force per unit width of rolled strip is the area under the pressure distribution curve, if the deformation is two-dimensional. Since the direct result of theoretical calculations (*e.g.*, Orowan[3]) is always the pressure distribution curve, measurements giving only the area under this curve can merely provide a very indirect test of the method of calculation, even if the yield stress and the coefficient of friction, as well as their variation over the arc of contact, could be obtained from independent measurements. The coefficient of friction can be derived from the slope of the roll-pressure distribution curve,[3] but if the roll force only is measured, the coefficient of friction becomes an unknown constant or (if it varies along the arc of contact) an unknown function in the evaluation of the experimental results.

Another limitation of the simple roll-force measurement may arise from roll flattening. It has been shown experimentally and theoretically[3] that the flattened arc of contact is not necessarily circular but may have

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Dr. Smith is in the Department of Radiotherapeutics, University of Cambridge. Dr. Scott is now in Sheffield. Mr. Sylwestrowicz is on the staff of Brown University, Providence, U.S.A. The authors were formerly in the Cavendish Laboratory, University of Cambridge.

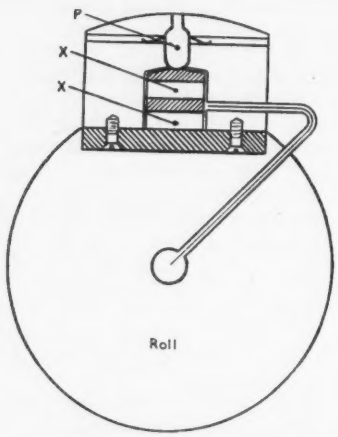


Fig. 1—Siebel and Lueg's apparatus

a hump at the neutral point ; consequently, Hitchcock's formula,[4] which assumes that the flattened arc of contact is circular, cannot give accurately its length. From roll-force measurements alone, therefore, even the mean roll pressure cannot be obtained, because the actual area of contact of the flattened roll is not accurately known. The measured roll force contains the purely elastic pressure at the entry and exit regions (where the pressure builds up to, or decreases from, the value at which plastic deformation begins or ends). These areas of purely elastic pressure (not to be confused with the purely elastic region around the neutral point—*cf.* Orowan,[3] p. 153) have not been considered in any of the existing treatments of rolling, yet they can be responsible for a considerable fraction, or even the whole, of the roll force. For example, no further reduction can be obtained with rolls of a given diameter, however strongly they are pressed together, if the thickness of the rolled stock reaches a certain lower limit ; in such cases, the entire roll force is purely elastic, and the plastic part of the arc of contact, to which the usual roll-pressure calculations refer, disappears entirely.

The roll-pressure distribution has not, so far, been calculated for the three-dimensional case (when the rolled stock is not very wide compared with its thickness), and accurate information can only be obtained by direct measurement.

The aim of the present work is to investigate the variation of pressure distribution over the whole area of contact between the rolled stock and rolls, for hot rolling and cold rolling both with and without applied back tension. From the results obtained, computations have been made to check calculations based on Orowan's method.[3] The authors realize that the comparisons with other methods of calculation are not complete, and that a wider range of materials might have been used with a larger range of reductions ; in particular, the scope of the hot-rolling experiments might have been extended. This has not been possible, however, as the authors have now left the Cavendish Laboratory. Nevertheless, it was thought advisable to publish the results so far obtained, for the benefit of future investigators in this field.

In addition to the above-mentioned work, the conditions under which the rolled strip spreads laterally and the effect of this on the pressure distribution have also been investigated experimentally. This problem has not yet been solved theoretically, and these results therefore may be useful when such calculations are made.

APPARATUS AND METHOD OF MEASUREMENT

The experimental rolling mill was a special two-high mill with 16-cm. dia. rolls driven by a variable-speed 20-h.p. Schrager motor, by means of which the rolling speed was kept constant at approximately 15 m./min.

The lower roll was specially fabricated to contain a photoelastic dynamometer ; it was fitted with a 0·7-mm. dia. tungsten radial pin, which transmitted

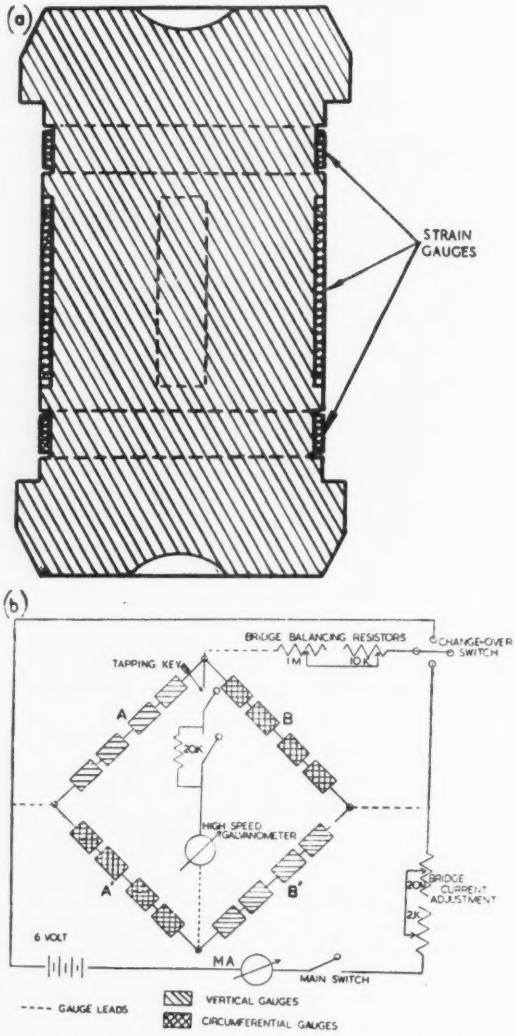


Fig. 2—Total roll-force measuring blocks: (*a*) Section of block; (*b*) blocks arranged in arms of Wheatstone bridge

the pressure on to the dynamometer, a detailed description of which has been published elsewhere.[5] Siebel and Lueg also used a pressure transmitting pin, which fitted accurately into a radial hole; the outer end of the pin was flush with the roll face, and the inner end pressed upon a piezoelectric crystal placed inside the roll. Their design is shown in Fig. 1. Siebel and Lueg's greatest difficulty arose from the finite width of the pin (2 mm. × 2 mm. square section); the measured pressure was the mean pressure over a part of the arc of contact equal to the width of the pin. They found that, since the length of the arc of contact was of the order of 8 or 9 mm., the correction was large and could only be made accurately enough by recording, with the pressure distribution curve, its first derivative. This was carried out by means of an electrical differentiation of the piezoelectric signal. In the present dynamometer, the 0·7-mm. dia. pin is equivalent, so far as the recorded curve is concerned, to a square pin of about 0·5 mm. width. With such a thin pin the correction is so small that it is significant only at points of sharp curvature, such as the points of entry or exit or the neutral point. The method of correcting for the finite size of the pin is described in Appendix II.

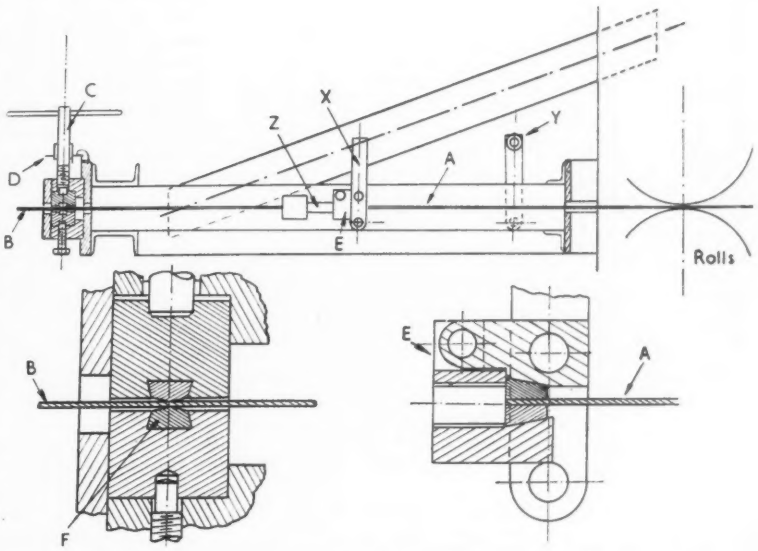


Fig. 3—Device for application and measurement of back tension

The photoelastic method[5] is, in some respects, more convenient than the piezoelectric method; it is capable of higher sensitivity, and it eliminates the use of slip rings. Drift due to electrical leakage, such as was experienced by Siebel and Lueg, may also be eliminated by using D.C. amplification of the signals, but the authors preferred to use simple resistance–capacity coupled amplifiers, and then to apply a small correction for electrical leakage (*see* Appendix I). The output from the amplifier was applied to one pair of plates on a cathode ray oscillograph, the time base of which was triggered just before the pin came into contact with the rolled stock. Contacts were attached to the roll at a fixed angular distance apart and it was arranged that each contact, when made, produced a small deflection on the time base. Hence it was possible to measure the instantaneous angular velocity of the rolls at the instant of rolling. The traces on the oscilloscope were photographed with a plate camera. (This method of stress measurement, in slow loading, has been investigated at the Cavendish Laboratory by Los,[6] and the present work owes much to his experiments.)

The experimental rolling mill was also fitted with a roll-force indicator for measuring the total force separating the rolls during rolling, and with a device for applying back tension to the strip being rolled. The essential components of the roll force indicator[7] were two cylindrical steel blocks (Fig. 2*a*), each of which was placed between one of the upper roll bearings and the corresponding pressure screw. These blocks were fitted with resistance strain gauges and were connected in a Wheatstone bridge (Fig. 2*b*). This arrangement compensated both for fluctuations of the temperature of the blocks and for any eccentricity of the load. The 'off-balance' deflection, which occurred when the gauge block was compressed, was measured by a high-speed reflecting galvanometer (period 0·1 sec.) and was recorded on photographic paper. The gauge blocks were calibrated by compressing them with known loads in a weight-loading testing machine and then recording the off-balance deflection.

Two methods are available for calibrating the photoelastic dynamometer. In the first,[5] a weight on a lever arm is used to apply a force directly on to the pin. By releasing the weight quickly, a deflection of the cathode ray tube trace is produced, which can be either measured directly or photographed, so that the deflection can be calibrated directly in terms of pressure between the rolls and rolled stock. In the second method, the total roll force measured by the roll force indicator is compared with the value obtained by integrating the roll pressure over the area of contact. These measurements are discussed on p. 353.

Application of Back Tension

The device* used to apply and measure the back tension on the rolled strip (*see* Fig. 3) is very useful, because it is not necessary to roll strips more than about 1 m. long to obtain a complete set of observations both with and without applied back tension. The frame of the apparatus fits on to the entry side of the mill, and back tension is applied to the rolled strip *A* by drawing a second strip *B* through a pair

* Designed by Mr. F. P. Stanton, formerly of the Rolling Mill Research Team of B.I.S.R.A. at Sheffield.

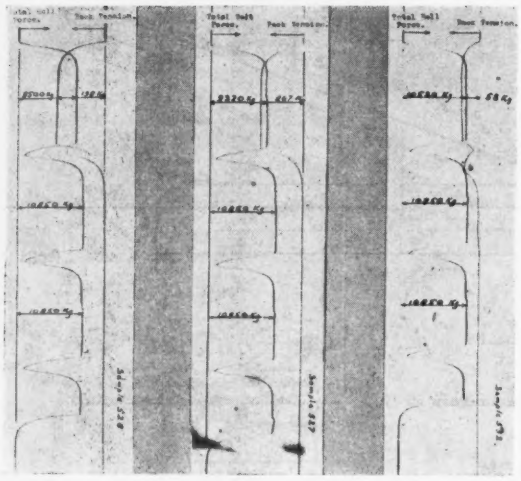


Fig. 4—Typical simultaneous recordings of roll force and back tension

of parallel dies *F*. The reduction that can be applied to the second strip *B* can be varied from zero up to a maximum of 1 mm. for a maximum permissible initial thickness of 2 mm. The applied back tension may be varied by (i) altering the width of the strip *B* used; (ii) changing the reduction by means of the screw *C*, with a calibrated scale *D* attached; or (iii) using a different metal for the strip *B*.

In this series of experiments, strips *B* were aluminium strips 2 mm. thick by 10, 20, or 30 mm. wide. The back-tension strip *B* was coupled to the strip *A* by means of the unit *E*, which was released automatically when the vertical bars *X* came into contact with the horizontal rods *Y*. This released the grips on *A*; the release mechanism *E* ceased to move further forward, and the rolled strip continued to pass through the roll gap, free.

Using aluminium strips with maximum dimensions as above, values of back tension up to 300 kg. could be applied.

The magnitude of the back tension was measured by observing the elastic strain produced in the cylindrical mild-steel rod *Z*. To this were attached four Baldwin Southwark *SR*4 120-ohm resistance strain gauges. Two were attached longitudinally and two circumferentially. The four gauges were connected together to form the four arms of a Wheatstone Bridge. Since all four gauges were on one specimen, the arrangement automatically compensated for any changes in the ambient temperature, and by placing the longitudinal and circumferential gauges in adjacent arms of the bridge, the extension of the former and contraction of the latter were additive and the sensitivity of the bridge was substantially increased. The bridge was calibrated separately by stressing the steel rod *Z* in a tensile testing machine.

The output from the bridge was measured by a high-speed reflecting galvanometer similar to that used for the roll force measurement, and the deflections were simultaneously recorded on the same sensitive paper moving at a speed of 5 cm./sec. Typical records are shown in Fig. 4. The periodic drop of both variables almost to zero occurred because the lower roll on the mill was not circular in section but, over a section of about 40°, was flattened (Fig. 5), to facilitate the attachment and adjustment of the photoelastic dynamometer placed inside this roll.

PRELIMINARY INVESTIGATIONS

Yield Stress

For the roll-pressure calculation it is necessary to know the yield stress of the material over the whole arc of contact. Assuming that the deformation can be regarded approximately as a homogeneous compression, the variation of the yield stress in cold rolling can be obtained from the reduction of thickness and the stress/strain curve of the material; in hot rolling, the stress is given by the rate of compression at the point of the arc of contact considered and by the (experimentally determined) relationship between compressive stress and rate of compression. (The reduction of thickness and the rate of compression have to be calculated from the real arc of contact, by considering the elastic deformations of roll and rolled stock.) In these experiments, however, an alternative and more direct method was used. This consisted of stopping the rolls with the rolled stock still between them, lifting the upper roll as quickly as possible, and measuring the variation of hardness along that part of the strip which bore the impression of the arc of contact (using a Vickers hardness testing machine). With ductile materials, the penetration hardness is determined by the yield-stress/strain curve of the material, and it has been shown[8] that there exists an approximate relationship between hardness and yield stress. With an 'ideally plastic,' *i.e.*, not hardening, material, an exact relationship would exist.

The approximate hardness/yield-stress curve (Fig. 6)

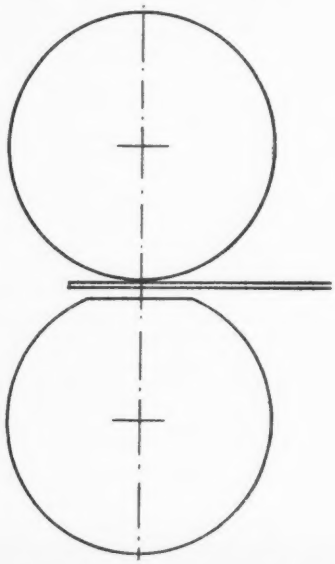


Fig. 5—Mill rolls, showing lower roll flattened to facilitate adjustment of dynamometer

was determined on copper strip specimens to which various degrees of deformation were given by cold rolling. The variation of the yield stress along the arc of contact in the rolling experiments was derived from the hardness measurements by means of this calibration curve ; the results agreed fairly well with values calculated from the stress/strain curve of the material and the known thickness of the strip at various points of the arc of contact.

Coefficient of Friction

Is is theoretically[3] possible to calculate the coefficient of friction μ, at entry and exit, from the slope of the pressure distribution curve at the points where plastic deformation begins or ends. In practice, this calculation is possible only for hot-rolling experiments, where a sharper discontinuity in the slope of the curve indicates clearly the beginning and end of the plastic region. In cold rolling, the transition is not sufficiently sharp for an accurate determination of the slope, and therefore of μ, to be made. For this reason, and also to obtain an independently determined value, the coefficient of friction at entry was calculated from a determination of the gripping angle ϕ. Figure 7 shows a strip on the point of entering the roll gap ; unless the resultant horizontal component of the forces acts inwards towards the gap, the strip will not ' grip ' and enter this gap. The condition for gripping is :

$$\mu s\cos\phi \geqslant s\sin\phi$$

which, in the limiting case when the strip just ' grips,' gives :

$$\mu = \tan\phi.$$

Copper strips, 40 mm. wide, were annealed, prepared, and treated in exactly the same way as those used in the later experiments (*see* p. 354). One end of each strip was carefully milled to be perpendicular to its length, and the distance between the rolls was gradually increased until the strip just gripped and passed into the roll gap. With a roll gap h_0 and initial strip thickness h :

$$\cos\phi = 1 - \frac{h - h_0}{D},$$

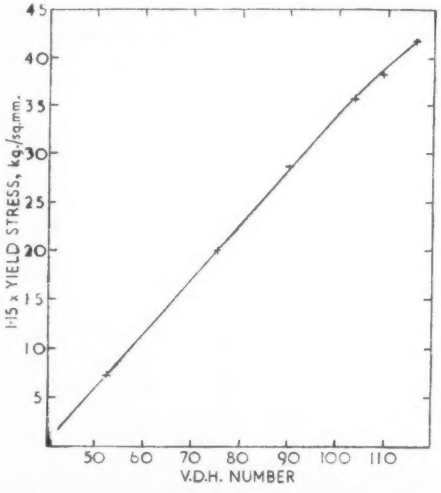


Fig. 6—Approximate hardness yield-stress curve for cold-rolled copper strips

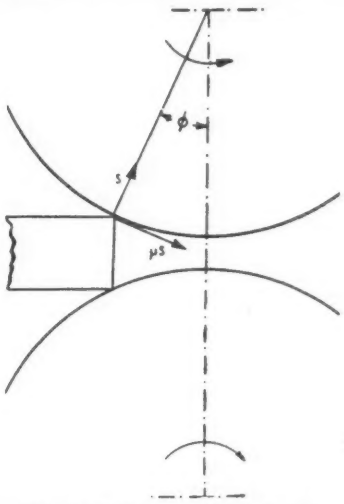


Fig. 7—Strip entering roll gap

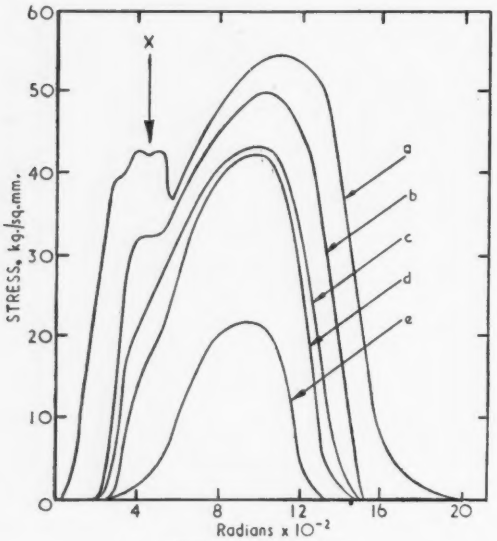
where D = roll diameter (= 16 cm.). By this means the coefficient of friction μ at entry, between dry rolls and annealed copper, was found to be $0{\cdot}1 \pm 0{\cdot}01$ for the early experiments (5% and 10% reductions) and $0{\cdot}12 \pm 0{\cdot}01$ for the later experiments (reductions greater than 20%).

These values are in good agreement with other determinations[9, 10] which either assume that the coefficient of friction is constant over the arc of contact, or determine its average value. It is probable, therefore, that μ does not vary appreciably across the arc of contact, and the values obtained in the present work have been taken generally as average values over the whole arc of contact.

Protrusion of Recording Pin

Although the roll and dynamometer assembly had been designed to have approximately the same elasticity, it was noticed during the experiments that the pin always protruded slightly above the roll surface when in contact with the rolled stock. Experiments were therefore carried out to determine how far the pin protruded and what effect, if any, this may have had on the shape, magnitude, and general characteristics of the observed pressure distribution curves.

During the cold rolling of annealed copper, the highest recorded pressures occur very close to the point where the strip leaves the rolls, and it therefore seems reasonable to assume that the impression which the pin leaves on the copper strip after rolling is an approximate measure of its greatest penetration during rolling. The depth of penetration was determined by observing the surface of the strip, after rolling, under a microscope at a magnification of 200, focusing first on the strip surface and then on the bottom of the pin impress. By this means the penetration could be estimated to 0·001 mm. It was found that the pin always protruded above the roll surface, the projection increasing from 0·003 mm. at 10% reduction to 0·015 mm. at 70% reduction. Even at this highest reduction, the pin protruded only 2%



Curve	Pin Projection
a	0·150 mm.
b	0·052 mm.
c	0·026 mm.
d	0·009 mm.
e	− 0·172 mm.

Fig. 8—Recorded pressure distribution curves for varying pin projections

of its diameter. Nevertheless, it was essential to ensure that this small value did not materially change the observed pressure distribution from that which would be obtained with a pin that remained flush with the roll surface during the whole period of contact.

Fully annealed copper strips, 2 mm. thick × 40 mm. wide, were used, and the measurements of pressure distribution were made with a constant reduction of approximately 20%. To ensure that the conditions of each experiment were as nearly constant as possible, measurements were made of the initial and final stresses of the copper, both before and after rolling, from determinations of the Vickers Diamond Hardness (*see* p. 350). The variation in yield stress between one strip and another was so small that it had a negligible effect on the observed pressure distribution. Slight variations in reduction of thickness also occurred from strip to strip, but these never exceeded ± 0·5%.

Normally, to calibrate the photoelastic dynamometer (*see* p. 349) the pin is left protruding approximately 1 mm. above the roll surface, and is afterwards ground down until it is flush with the roll surface. In these experiments, however, records were taken during rolling with the pin protruding by amounts from 0·150 mm. to 0·009 mm. (The latter value occurred when the pin had been finally ground flush with the roll surface before rolling.) In one experiment the pin broke inside the roll, and a record was obtained with the pin recessed by a distance of 0·172 mm. beneath the roll surface.

The results are given in Fig. 8, which shows the recorded pressure distribution when the pin projected by amounts from 0·150 mm. to − 0·172 mm. The maximum stress recorded increased with the projection of the pin, the increase being slow at first and then more rapid. At projections of 0·009–0·026 mm., the increase in the maximum stress recorded is less than 5%; therefore, if the pin protrudes less than 0·026 mm., the error in the maximum stress recorded is less than 3%. Figure 9 indicates how the area under the curve, which is used in calculating the integrated roll pressure (*see* p. 353), varied with pin projection. At projections of up to 0·025 mm. the curve is reasonably horizontal, and the increase in area is less than 6%; between 0·025 mm. and 0·10 mm. there is a steep rise to a value approximately twice the initial value; and for projections greater than 0·10 mm. the curve again begins to flatten out at a higher level. The vertical arrow marks the maximum pin projection achieved in the experiments; the maximum possible difference between the area in this case and the area with the pin remaining absolutely flush, *i.e.*, when the curve is extrapolated to a pin projection of zero, is certainly less than 5%.

Another important feature is the effect of pin projection on the shape of the curve, and in particular on the 'knee' of the pressure distribution curve near the entry point (Fig. 8, point *X*). For large pin projections this knee is very pronounced and the pressure passes through a maximum before the main part of the curve is reached. For smaller pin projections the knee appears only as a point of inflection on the curve and occurs at a much lower stress; when the pin is recessed within the roll, even the point of inflection disappears. This feature is much more sensitive to the projection than is the area under the curve. Since, however, curves *c* and *d* in Fig. 8, corresponding to the two smallest positive pin heights, are so nearly of the same shape, it seems reasonable to suppose that they have become constant. There is therefore no reason to assume that these curves are appreciably different from those which would be obtained with a perfectly flush pin.

The authors feel confident that their results are in no way invalidated by the small amount by which the measuring pin protruded above the roll surface.

Calibration of Apparatus

To calibrate the photoelastic dynamometer by the second method given on p. 349, 2-mm. and 3-mm. thick 40-mm. wide annealed copper strips were given reductions in thickness of from 5% to 40%. For each

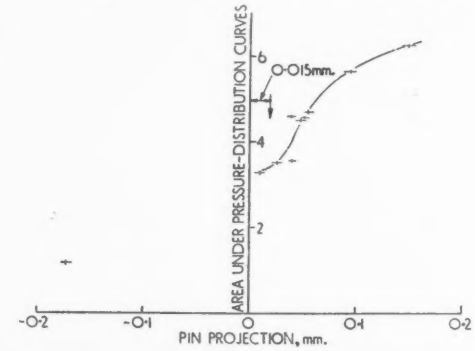


Fig. 9—Variation of area under pressure distribution curve with projection of pin

reduction a series of pressure distribution curves was recorded by rolling a set of exactly similar strips and varying across the strip the point at which the recording pin made contact, using the strip guides on the entry side of the mill, the positions of which could be adjusted in the transverse direction. The integration was carried out by computing the area of each of the curves and then plotting a graph (Fig. 10) with the areas as ordinates and the position across the strip as abscissae. The area of this graph, expressed in suitable units, gives the integrated total roll force to a very close degree of approximation. To obtain the exact roll force the *vertical pressure* should be integrated over the area of contact ; however, the error due to integrating the radial pressure as recorded is only of the order of 1%, which is less than the inaccuracies in other experimental measurements.

The comparison between the integrated roll force and the total roll force as measured directly by the lever arm method, for varying reductions of copper strip, is shown by the following figures :

Thickness of Strip, mm.	Reduction, %	Integrated Load, kg. (*A*)	Load Measured Directly, kg. (*B*)	*B*/*A*
3	5	2216 ± 200	2200 ± 300	1·00 ± 0·10
2	10	4320 ± 80	4445 ± 150	1·03 ± 0·05
2	20	8392 ± 150	7460 ± 300	0·89 ± 0·05
2	30	10,520 ± 200	9780 ± 155	0·93 ± 0·03
2	40	15,380 ± 300	12,080 ± 900	0·79 ± 0·09

Each value of the integrated roll load is the average of two complete sets of experiments at a given reduction of the strip.

The total load varies by a factor of approximately 6. At low reductions and loads the agreement is very good, but as the reduction and load increase the agreement becomes worse, until at the highest reduction there is an error of 20%. Further investigation has shown that this discrepancy arises from elastic distortion of the rolls, particularly at the thinnest part (3 mm.) of the roll surface near to the recording pin. The roll distortion causes a force to be impressed on the glass block, even when the pin is completely

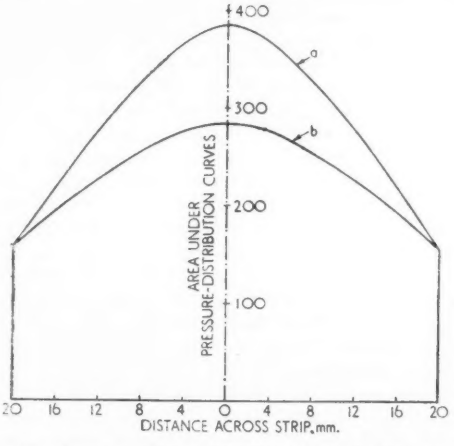


Fig. 10—Area under pressure distribution curves. Curve *a*: 44·5% reduction without back tension; curve *b*: 47·5% reduction with 3 kg./sq. mm. back tension

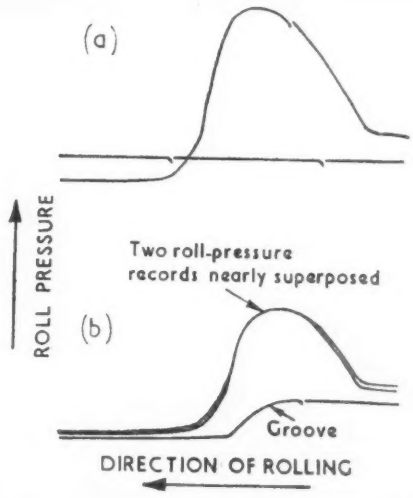


Fig. 11—Pressure distribution curves: (*a*) Effect of roll distortion at large reductions; (*b*) method of overcoming roll distortion

absent, and produces a deflection of the cathode ray tube trace. Fortunately, the effect is small and may be neglected at low reductions (< 20%). With large reductions (> 60–70%) the effect is very marked, as is shown in Fig. 11*a*, in which the level of the cathode ray tube trace is several millimetres lower at the exit point than at the entry point. This difficulty has been overcome by making two consecutive recordings of the pressure distribution. The first recording, carried out in the normal manner with the pin making contact with the rolled strip, includes the pressure impressed on the pin. The second recording is made on a part of the strip in which a longitudinal groove 2 mm. wide has been cut ; in this case the pressure recording pin does not come into contact with the strip, and the recorded pressure is due solely to the deformation of the rolls (*see* Fig. 11*b*). The difference between the two records gives the pressure on the pin. Using this method, the agreement between the roll force measured directly and that obtained by integration is greatly improved, as is shown by the following figures :

Reduction, %	Back Tension, kg.	Integrated Load, kg. (*A*)	Load Measured Directly, kg. (*B*)	*B*/*A*
44	Nil	12,100	12,000	0·99
47	258	9750	10,400	1·06
45	Nil	12,350	12,460	1·01
47	226	10,380	11,050	1·06
46·5	Nil	12,180	12,350	1·01
49	250	10,760	10,860	1·01

Cross-section of strip = 80 sq. mm.

This second check on the lever-arm method of calibration confirmed the value of the method, which was accordingly used for all the later work. For reductions of up to 20%, therefore, where roll deformation was negligible, the records were used directly, but for higher reductions a double record was taken, the true stress on the pin being obtained from the difference in the readings.

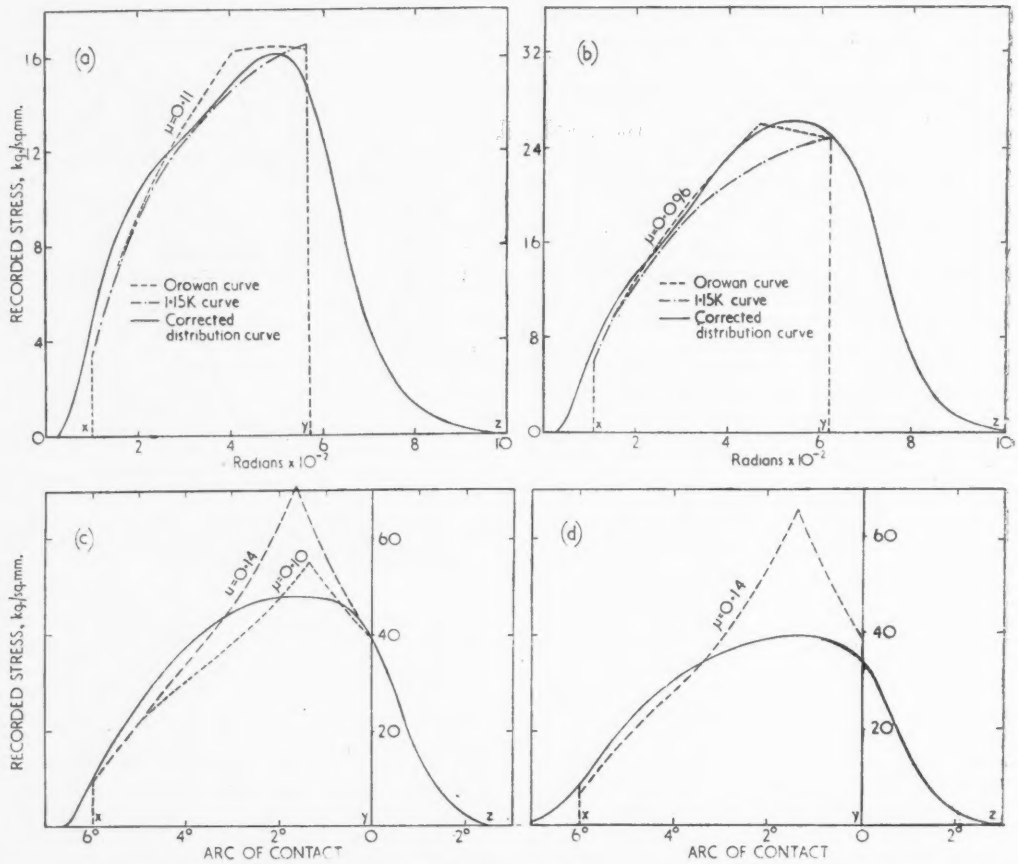


Fig. 12—Pressure distribution curves during cold rolling: (*a*) Reduction 5·5%; (*b*) reduction 10%; (*c*) reduction 41% without back tension; (*d*) reduction 44% with back tension

MAIN EXPERIMENTS

Cold Rolling

For this series of experiments, reductions of 5–50% were used, but back tension was applied only for reductions greater than 20%, the back tension and pressure distribution curves being recorded simultaneously. Fully annealed H.C. copper strip, 40 mm. wide × 2 mm. thick, was used, and the measuring pin always made contact within ± 1 mm. of the centre of the strip. (The lateral variation produced no observable change in the pressure distribution curve.) For each measurement both the rolls and rolled stock were cleaned with ether and made as free of oil as possible.

The computations on the records were then carried out as follows : The negatives of the original oscillogram photographs were enlarged in a photographic enlarger and were projected on to a sheet of graph paper, the curves being redrawn directly on the paper. For reductions above 20%, each record then consisted of three pressure-distribution curves, (i) without back tension, (ii) with back tension, and (iii) due to roll deformation—the pin not being in contact with the rolled stock. For reductions below 20%, since back tension was not applied, curve (i) was missing and curve (iii) was a horizontal straight line. The differences in the ordinates of curves (i) and (iii) and (i) and (ii) were replotted as ordinates with the abscissae in the same units as the abscissae of the original curves (*i.e.*, time). To these new curves were applied the appropriate corrections for electrical leakages and for the finite size of the pin (Appendixes I and II) ; the resulting curve was that of the true pressure distribution against time. The time units were then converted into angular units, from the known roll speed and the deformed radius of the roll as calculated from Hitchcock's formula.

The final curves were then compared with those calculated by Orowan's method. The points X and Y at which the recorded stress was 1·15 times the yield stresses at entry and exit, respectively, were marked on the curve (Figs. 12*a–d*). The fact that these two points almost coincided with the two points of greater curvature (where, presumably, plastic yield commences and ends) shows that the state of strain in the rolled stock in these experiments always approximated closely to homogeneous compression, because the figure 1·15 is obtained on such an assumption.[11]

The minimum thickness h_0 can be calculated from

the angular distance ϕ between the points X and Y, the deformed roll radius R', and the initial thickness h_m of the strip (*see* Fig. 13). The value of h_0 is necessary to calculate the parameter $\gamma = h_0/2R'$, which enters into the remaining computation. From γ and the measured final thickness h_0' of the strip, the angular length of the elastic part of the arc of contact on the exit side can be calculated. In every case there was very good agreement (within 5%) between the calculated value and that measured from the curve (*i.e.*, the distance YZ in Figs. 12*a–d*).

The computation of the theoretical shape of the pressure distribution curve was made using the method described by Orowan[3] and exemplified by Appendix I of his paper. The variation of yield stress over the arc of contact was taken as that given by the hardness measurements, and the roll radius used was that given by Hitchcock's formula. Bland[12] has shown, theoretically, that this formula gives as accurate a value as is possible without extremely laborious calculations. The pressure distribution curves were calculated for a few assumed values of the coefficient of friction, and the value noted on each curve was that which, it was considered, gave the best fit with the experimental curve. Each experimental curve was the mean of five observations made on identically similar strips under the same conditions of reduction.

Very good agreement was obtained for 5% and 10% reductions and μ values of 0·11 and 0·096, respectively. This agrees, within experimental error, with the value of $\mu = 0{\cdot}1 \pm 0{\cdot}01$ obtained from the gripping angle, and also with the values 0·09–0·13 obtained by Hoff and Orowan,[13] using a very different method, for copper between steel rolls.

In the later experiments at higher reductions, the agreement between the value (0·12–0·14) giving the best fit to the experimental curves, and the value ($0{\cdot}12 \pm 0{\cdot}01$) obtained from the gripping angle is not so good. This is probably because, towards the end of the experiments, the roll surface near the pin was becoming locally rather rougher than the remainder, owing to the grinding down of about 20–30

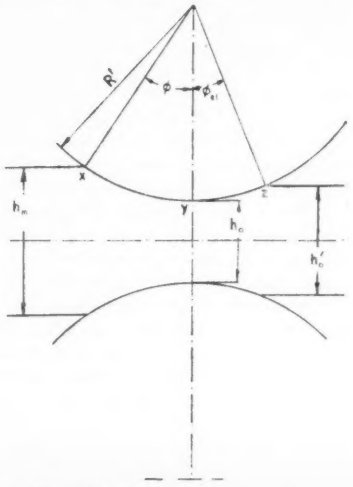


Fig. 13—Strip between rolls

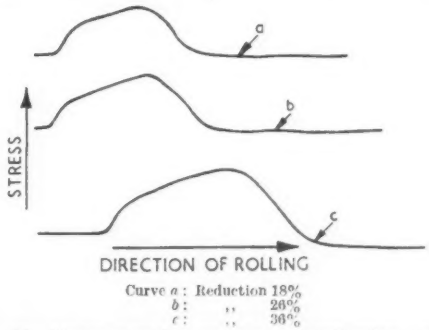


Fig. 14—Uncorrected pressure distribution curves during hot rolling

measuring pins. The gripping angle gives the average value of the coefficient of friction over the whole width of the strip, because at the instant of gripping the edge of the strip is wholly in contact with the smooth roll surface. On the other hand, the forces registered by the pin must to a large extent be governed by local conditions in the neighbourhood of the pin, and if the roll surface there has been slightly roughened the local coefficient of friction might very easily be 0·14 when the average was 0·12.

Hot Rolling

This series of experiments was not exhaustive in its scope, but it enabled a check to be made of the calculations relevant to hot rolling, where the coefficient of friction and hence the frictional contribution to the total roll force are much higher than in cold rolling.

It was not possible to apply back tension in hot rolling, because it takes several minutes to attach the strips into the clips E (Fig. 3) and to put them into a position for rolling. During this time the strip cools by several hundred degrees, so that it can no longer be considered as having been rolled hot.

The specimens for rolling consisted of copper strips (similar in size to those used for cold rolling) which were furnace-annealed for ½–1 hr. at 900° C. The furnace, which had a large door, was placed close to the entry side of the mill, and at the required instant the strips were rapidly taken out of the furnace, placed quickly between the mill guides, and rolled. Even with this method the drop in temperature must have been considerable, and the estimated temperature is probably only accurate to within ± 50° C. The specimens could not be conveniently heated in a vacuum furnace and were therefore covered with a thin scale of copper oxide at the instant of rolling. Records were taken only at the centres of the strips, because of the technical difficulties inherent in reproducing the conditions exactly.

Typical records are shown in Fig. 14, and corrected curves are given in Fig. 15. The sharp changes in curvature near the beginning and end of the curve, where elastic deformation ends and plastic deformation begins, are much more obvious and well-marked than in the case of cold rolling. This is due to the greater softness of the material rolled, which produces less elastic deformation, and to the higher coefficient of friction, which leads to a steeper initial rise of the

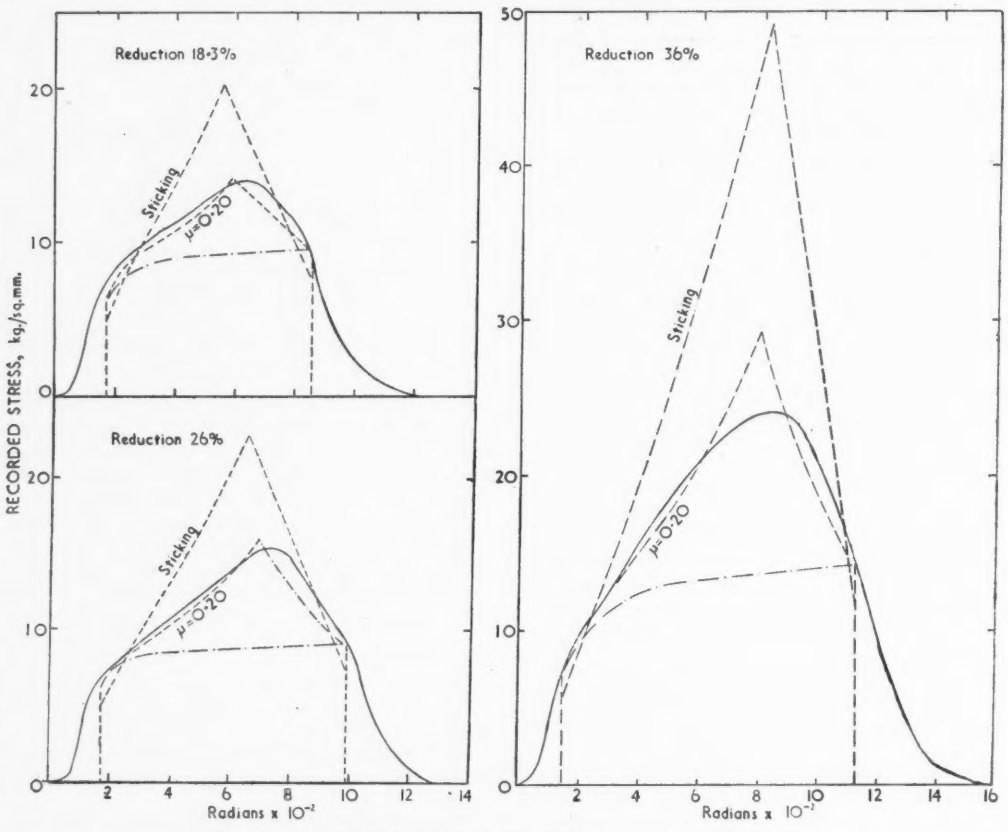


Fig. 15—Corrected pressure distribution curves at 800° C.

'friction hill' (*see* Orowan,[3] p. 143). (Compare Figs. 12 and 15.)

Figure 15 shows that the pressure at the point of exit is higher than that at the point of entry—even though the rate of compression is higher at the entry—and that the yield stress at a given temperature increases only with the rate of deformation. It is obvious that the strip cools down and so becomes harder as it moves forward in contact with the cold roll surface.

To calculate the pressure distribution it was assumed that plastic yielding began and ended at the points of rapid change in curvature near the beginning and end of the curve. This assumption seems reasonable, because the angular distance between the points agrees with the length of the arc of contact calculated from the initial and final thickness of the rolled stock and the roll radius. Calculations were then made for suitable values of the coefficient of friction (*cf.* Orowan's calculations on Siebel and Lueg's hot-rolling results), and it was found that the best fit occurred in all the experiments with a value of $\mu = 0{\cdot}2$. For these calculations it was necessary to assume, rather arbitrarily, the form of the curve giving the variation of yield stress along the arc of contact. This is unknown—only the initial and final values are fixed. However, it was found that the calculated pressure distribution curve was not sensibly affected by small changes in the form of the variation of yield stress assumed.

DISCUSSION

The most important feature is the good agreement, in all cases, between the curves calculated by the Orowan method and those observed experimentally. Other noticeable features are the way in which the total roll load falls as back tension is applied, and the fact that the neutral point moves towards the exit plane when back tension is applied. Both these features can be predicted from simple theoretical considerations, and Bland has devised a method of determining the coefficient of friction by observing the value of the back tension at which the strip just fails to continue to be rolled, *i.e.*, when the neutral point coincides with the exit plane.

Good agreement between the calculated and observed curves cannot be expected in the region of the neutral plane; as Orowan has pointed out, the experimental curve is rounded and does not come to a peak at the neutral point, because of the zone of non-plastic deformation. Calculations to determine the exact shape of the curve in this region have not yet been made, and are in any case extremely difficult.

Another feature is obvious from Fig. 16. At reductions greater than 20% it is seen that the shape of,

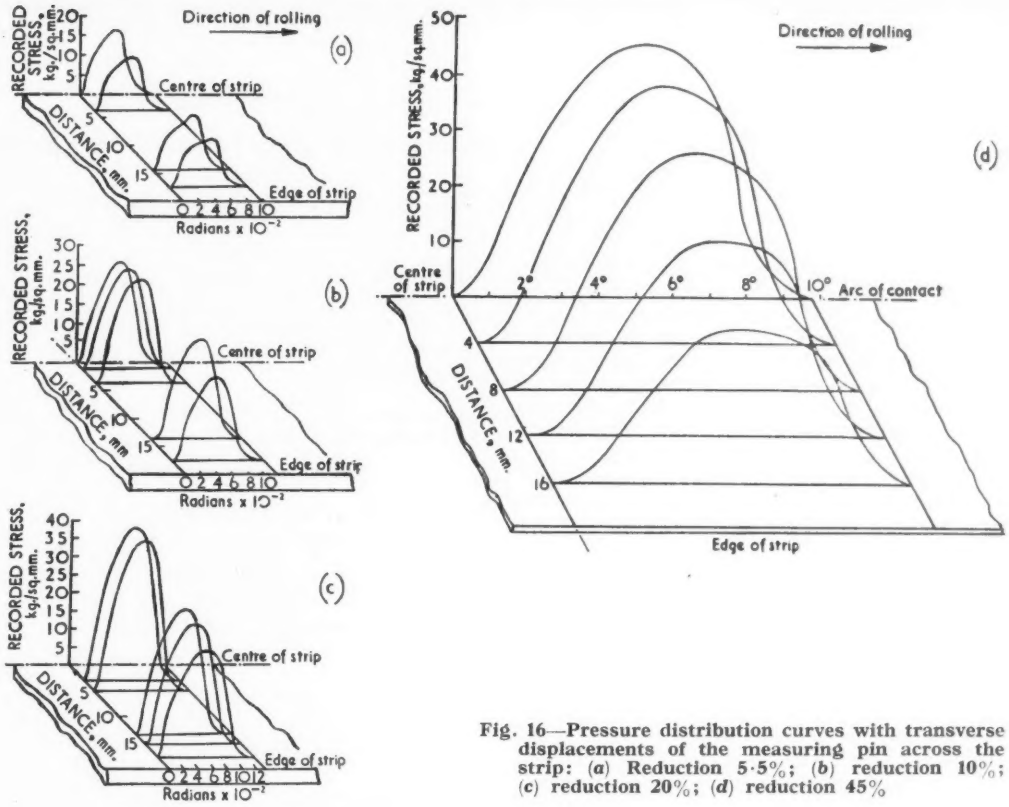


Fig. 16—Pressure distribution curves with transverse displacements of the measuring pin across the strip: (*a*) Reduction 5·5%; (*b*) reduction 10%; (*c*) reduction 20%; (*d*) reduction 45%

and the area under, the pressure distribution curve change markedly for a small transverse displacement of the measuring pin from the centre of the strip. Only at the smallest reductions is the condition of plane strain satisfied. Orowan, in his calculations, assumed that this condition would be satisfied in cases where the strip width is greater than 6–8 times the thickness ; in the present work the width (40 mm.) is 20 times the thickness, and the effect is quite appreciable for reductions greater than 20%. The transverse drop of roll pressure extends particularly far from the edges of the strip if the coefficient of friction is low ; nevertheless, the question of the transverse drop needs renewed consideration from the point of view of practical roll-force calculations.

Calculations of total roll load have previously taken into account only the plastic parts of the pressure distribution curve, and have not included the regions of elastic compression close to the planes of entry and exit. The contribution of the elastic part of the curve can be considerable (*see* Fig. 12), and it must be emphasized that estimates of the total roll load made solely from calculations on the plastic part of the curve may be very much in error. In fact, when 'limiting' reduction has been reached the whole of the roll force may be due to the elastic deformation of the stock and rolls (*see* p. 348).

To confirm that this series of experiments was carried out under conditions in which the roll flattening was very small, the shape of the arc of contact was determined by a direct and apparently accurate method. The rolling mill was stopped while the strip was still between the rolls, the upper roll was lifted as quickly as possible, and the shape of the impression of the rolls on the strip was measured with a Talysurf apparatus. The curves obtained show that for reductions up to 10% the arc of contact remained circular, its radius of curvature being approximately equal to the nominal roll radius. During the time of deceleration and until the upper roll had been lifted, some creep occurred, but for small and moderate reductions this appears to be unimportant.

The point of entry could be recognized visually as a clearly marked line on the partly rolled specimens. The Talysurf measurements, however, indicated a slight reduction of thickness just before the strip came into contact with the rolls. Hardness measurements in this region (just in front of the line of entry) showed a slight increase above the value for the initial material ; this may have been (at least partly) because part of the plastically deformed region around the hardness indentation was within the arc of contact, and so the hardness number obtained was slightly higher than would correspond to the actual hardness of the material in the centre of the indentation.

The length of the diagonal of the Vickers prism

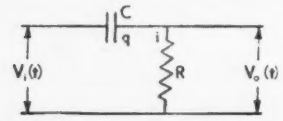


Fig. 17—Diagram of coupling circuit

indentation in the direction of rolling was greater than that of the transverse diagonal. The difference between them gives a convenient measure of the anisotropy of the yield stress produced by rolling. For small reductions the difference tended to vanish as the edge of the strip was approached ; this is clearly because the free lateral spread at the edges eliminated the difference between the direction of rolling and the transverse direction. At higher reductions this approximate equality of the diagonals at the edge was not observed, and, in spite of the free spread, the principal extensions in the rolling and the transverse directions were unequal.

It was observed that the hardness number derived from the mean value of the two diagonals increased perceptibly towards the edges, although it remained fairly constant around the middle of the strip. This may have been because the thickness of the rolled strip decreased, and so the reduction of thickness increased towards the edges.

Acknowledgments

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APPENDIX I

Correction for Time Constants of Coupling Circuits

Consider the circuit shown in Fig. 17, having an applied potential $V_i(t)$ which is a function of the time t. The output potential $V_0(t)$ will not be an exact replica of V_i. The distortion can be calculated as follows.

At any instant, the charge q on the condenser C and the current i flowing round the circuit are given by the equation :

$$\frac{q}{C} + Ri = V_i$$

$$i.e.,\ V_i - V_0 = \frac{q}{C} = \frac{1}{C}\int_0^t i\,dt,$$

since $V_0 = Ri$. This can be written :

$$V_i - V_0 = \frac{1}{RC}\int_0^t Ri\,dt$$

$$= \frac{1}{RC}\int_0^t V_0\,dt$$

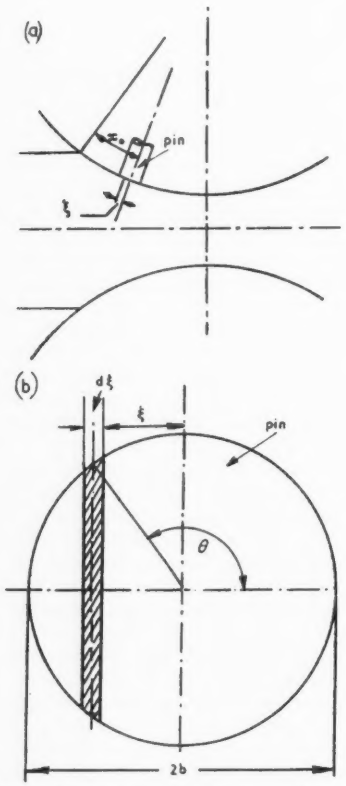


Fig. 18—Terminology used in correction for finite width of pin

With n intervalve coupling circuits using capacities and resistances C_n and R_n, the drop in potential at the pth stage is :

$$\Delta V_p = {}_pV_i - {}_pV_o = \frac{1}{C_pR_p}\int_0^t {}_pV_o\,dt$$

For the whole n stages, therefore, the correction is given by :

$$\Delta V = \sum_{n=1}^{n=p} \frac{1}{C_pR_p}\int_0^t {}_pV_o\,dt$$

If ΔV is small compared with $V_0(t)$, the term ${}_pV_0$ can be replaced, with only small error, by ${}_nV_0$, the final output. The expression for ΔV then becomes :

$$\Delta V = \int_0^t {}_nV_0\,dt.\sum_{p=1}^{p=n} \frac{1}{C_pR_p}$$

This integration can easily be carried out numerically, and the correction at each point of the curve may then be obtained.

APPENDIX II

Correction for Finite Width of Pin

In Fig. 18, let x_0 denote the distance of the centre of the pin from the point of entry along the arc of contact, and let ξ be a parameter denoting the linear distance of any other point on the pin from the centre.

If $f(x)$ is the true pressure distribution function, which would be recorded if the pin were infinitesimally small, and if $\phi(x)$ is the experimentally observed function, then :

$$\phi(x_0) = \frac{1}{\pi b^2}\int_{\xi=T}^{\xi=b} -f(x_0+\xi).2b^2\sin^2\theta\,d\theta.$$

where $\xi = b\cos\theta$ and b is the radius of the pin.

Expanding by means of Taylor's theorem and putting $\xi = b\cos\theta$, the equation becomes :

$$\phi(x_0) = -\frac{2}{\pi}\int_{\xi=T}^{\xi=b}\left\{f(x_0)\sin^2\theta d\theta + b\cos\theta f'(x_0)\sin^2\theta d\theta + \frac{b^2\cos^2\theta}{2!}f''(x_0)\sin^2\theta d\theta\ldots\right\}$$

Since x_0 is constant for each integration, this equation may be written :

$$\phi(x_0) = -\frac{2}{\pi}\left\{f(x_0)\int_{\xi=T}^{\xi=b}\sin^2\theta d\theta + bf'(x_0)\int_{\xi=T}^{\xi=b}\sin^2\theta\cos\theta d\theta + \frac{b^2}{2!}f''(x_0)\int_{\xi=T}^{\xi=b}\sin^2\theta\cos^2\theta d\theta\ldots\right\}$$

The limits of integration are $\xi = T$ and $\xi = b$, where T is equal to either $-x_0$ or $-b$, whichever is the greater.

Consider first the case when $x > b$; the limits of integration are from $\xi = -b$ to $\xi = +b$, *i.e.*, $\theta = \pi$ to $\theta = 0$. The integration is simple, and the equation reduces to :

$$\phi(x_0) = f(x_0) + \frac{b^2}{8}f''(x_0) + \text{terms in } b^4,\ b^6, \text{ etc.} \quad \ldots(1)$$

Equation (1) can be converted into an explicit expression for $f(x_0)$, as follows :

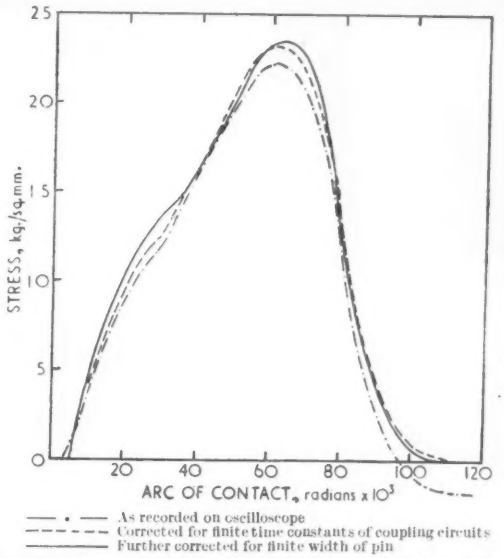


Fig. 19—Curve of Fig. 12*b* replotted with and without corrections

$$f(x_0) = \phi(x_0) - \frac{b^2}{8}f''(x_0) \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Differentiating twice :

$$f''(x_0) = \phi''(x_0) - \frac{b^2}{8}f''''(x_0)$$

and substituting for $f''(x_0)$ in equation (2) :

$$f(x_0) = \phi(x_0) - \frac{b^2}{8}\phi''(x_0) + \frac{b^4}{64}f''''(x_0) - \ldots\ldots\ldots$$

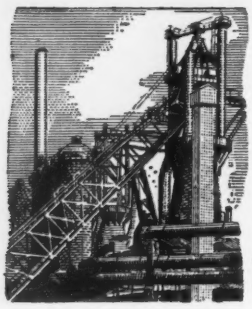
$$= \phi(x_0) - \frac{b^2}{8}\phi''(x_0), \text{ neglecting terms above } b^2.$$

This simple correction may be applied where it is valid, by numerical computation at each point on the curve. The correction is not valid for values of $x_0 < 2b$, because the limits of integration are no longer $\theta = 0$ to $\theta = \pi$. By a similar argument it can be shown that, under these conditions and taking the limits $\theta = 0$ to $\theta = \alpha$, the correction becomes :

$$f(x_0) = \phi(x_0)\left\{\frac{\pi}{\alpha + \frac{1}{2}\sin 2\alpha}\right\} - \phi'(x_0)\left\{\frac{b.\frac{2}{3}\sin^3\alpha}{\alpha + \frac{1}{2}\sin 2\alpha}\right\}^2$$

This correction can be applied only at the beginning and end of the curve and is, in practice, negligibly small. Within the accuracy of the experiments, its effect is merely to shorten the corrected arc of contact to be $2b$ less than the observed one. Since, on the corrected curve, the end-point is known accurately, the initial point can now be fixed, and the extrapolation back from the last point of the curve for $x > 2b$ to this point cannot be more than an extremely small amount in error. The first correction calculated can then be applied over the remainder of the curve.

Figure 19 shows the curve of Fig. 12*b* replotted without applying any correction. The other two curves in this figure show the effect of applying, successively, the two corrections.



IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP

Pump Design and Application in Iron and Steel Works

By C. G. Evans

SYNOPSIS

Design and application of pumping plant are dealt with and the need for careful consideration of particular requirements before installation is emphasized.

Suction conditions including cavitation are discussed, followed by a brief description of methods that avoid certain difficulties. The effects of varying head conditions caused by multiple/solo operation, the results of frequency variations, the dangers of reduced load, and methods of suitably adapting installed units to varying conditions are also described.

Various means of applying automatic control both on suction and delivery sides, are enumerated, including pressure and other methods of control without electrical transmission from the distant reservoir or tank, and details of both instrumentation and analysis of pump and duty faults are given. A list of the available types of centrifugal pump is provided.

THE paper deals with pumps from the viewpoint of the manufacturer and designer rather than from that of the actual operator, and is confined to units in hydro-kinetic systems, which transfer liquid from one point to another or depend upon the use of fluid as a vehicle of kinetic energy. These are now mainly restricted to the centrifugal pump, which has taken over most of the pumping duties in the industry.

DESIGN REQUIREMENTS

The mechanical and hydraulic design features of a pumping installation should be suited to the requirements of the work to be expected from it. Thus, when an order is placed, the manufacturer should be supplied with details such as gallonage and head to be generated, the motive power, the static lift and friction on both suction and delivery sides—together with their possible variation or alternative duties—and whether solo or parallel operation is to be employed.

SUCTION CONDITIONS

Head Required

Many operational faults can be traced to suction conditions. Suction lift consists of the static height from the water level to the pump centre-line, together with all friction and velocity losses in the suction pipeline (including valves and bends) and the velocity head at the pump suction branch. It should be made clear whether the lift is measured from floor level or from some assumed height of centre-line, and the top and bottom water levels should be stated. Figure 1 shows the available suction performance of a centrifugal pump.

The losses between the suction branch and the inlet blading of the impeller—consisting of friction, shock and eddy losses, and change of velocity from that in the branch to that in the impeller blade inlet—vary approximately as the square of the quantity flowing. Although the full 34 ft. (30-in. barometer) minus ½-in. Hg vapour pressure should be available at no-flow with cold water, it is usually found that the practical figure is about 30 ft. This will fall as the quantity flowing increases because of the corresponding increase in the pump inlet losses. The resultant curve represents the cavitation line of the pump measured at the branch, above which it cannot operate, because sufficient head is not available to force the water into the pump. For quantities beyond that at which the curve crosses the zero head-line, a positive head is required to make water flow into the pump, even under cavitation conditions. A unit working at or close to cavitation for any considerable period is liable to severe corrosion and fatigue failure, and it is therefore necessary to provide a marginal head of about 10 ft. on normal sizes and speeds.

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The safe operational curve is also shown in Fig. 1. From this can be ascertained the maximum quantity that a particular pump can safely handle at a given static lift, or alternatively by interpolation, the maximum static lift (or minimum positive static) that is permissible for the handling of a required gallonage.

The upper curves in Fig. 1, showing the head/volume performance of a pump, fall away steeply when cavitation conditions apply. The friction-curve intersections show the reduction in capacity of a pump subjected to such cavitation.

The permissible suction conditions must be varied according to altitude, temperature, size, and speed of the unit. Thus, suction is decreased by about 1 ft. head for every 1000 ft. of altitude above sea level and the suction lift is decreased by 1 ft. (or the positive head increased by 1 ft.) for every foot of vapour pressure above that of cold water. With water at 212° F. the vapour pressure is that of the atmosphere, *i.e.*, an absolute pressure of 14·7 lb./sq. in. (36 ft. at a sp. gr. of 0·96) and so the suction head is increased by 36 ft. Where the liquid has a specific gravity greater than unity, the suction lift is again adversely affected (inversely as the sp. gr.).

Sometimes the phrase ' net positive suction head ' (NPSH) is used. It is defined as the difference between the total inlet head (including the velocity head in the inlet) and the head corresponding to the vapour pressure of the liquid pumped at the operative temperature ; it is thus not the actual suction gauge head but is its excess over that of vapour pressure.

Flow Pipe and Sump Layout

Care is needed in the positioning of the flow pipes. The soffit or top of the suction-pipe bore should never dip towards the pump if there is a suction lift and

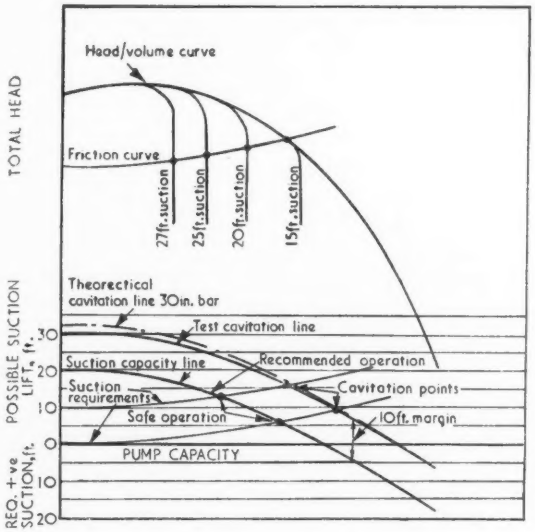


Fig. 1—Suction performance—showing the effect of cavitation on the head/volume curve and also safe operation and cavitation values in cold water

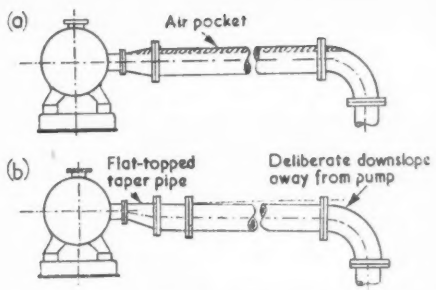


Fig. 2—Suction layout: (*a*) poor, with regular taper and horizontal suction line; (*b*) good, avoiding air pockets

preferably should rise continuously to the suction branch (*see* Fig. 2). A long pipe system should be deliberately laid on a rising gradient, to prevent air or water vapour being trapped and later drawn through to the pump in gulps.

It is bad practice to use a common suction pipe for several pumps when there is a suction lift. The running pumps may draw air through the glands of the standing units or through those of the sluice valves required to isolate the pumps. Again, it is difficult to prime the standing pump unless a non-return or sluice valve is inserted in each leg of the suction system at a point below the hydraulic level of the supply system to enable a full prime back to be accomplished (Fig. 3).

Where it is required to operate at times with water in the suction reservoir, tank, or culvert at a very low level, special shallow strainers with large total hole areas are necessary. Anti-vortex plates are a decided advantage (Fig. 4).

Where pumps are placed in dry sumps or underground rooms below the suction liquid and drain level it is necessary to deal easily with gland seepage and

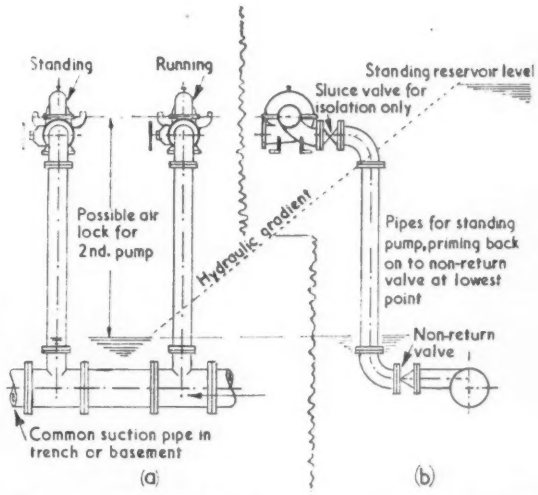


Fig. 3—Priming difficulties with common suction pipe and positive static suction. (*a*) Bad layout; (*b*) good layout

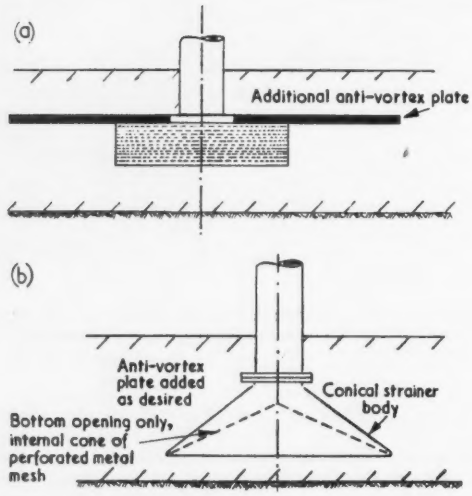


Fig. 4—Anti-vortex plates (*a*) with large-area shallow cheese-type strainer, (*b*) with conical strainer for extreme drawn-down

leaks. A small sump should be formed for the collection of the liquid and an auxiliary suction pipe and valve provided as indicated in Fig. 5. By throttling of the main suction sluice valve to create a temporary vacuum, the small suction valve may be opened and the seepage drawn into the main flow. When the sump is emptied the valves should be returned to normal position.

Priming Methods

Priming of the pump is intimately connected with the suction conditions. Where the delivery system is under continuous pressure, by-pass priming on to a foot valve or non-return valve below water level is a simple solution.

There are many cases where foot valves are either unsuitable or undesirable. In such cases priming has to be accomplished by evacuation, which can be by various methods. If air, steam, or water pressure is readily available a plain ejector can be used ; otherwise air or water pressure can be provided locally from a compressor or small water pump and auxiliary tank. Rotary exhausters can also be used, but in such cases it is advisable to provide a barometric leg or water-collecting vacuum vessel between the pump and the exhauster to prevent the carry-over of water to the exhauster, which would thereby suffer damage. On small sets, hand priming by evacuation can be carried out by a good-quality semi-rotary wing pump.

Where solid-bearing waters are to be handled it is better to place the pump so that a flooded or positive suction is available. Sticking or jamming foot valves are thus avoided and no complications with priming apparatus are encountered (Fig. 5).

DELIVERY CONDITIONS

It is advisable to consider not only the total calculated head but also the static and frictional components. The calculations should also include the losses in the valves and pipe connections inside the pump house itself, or their omission should be clearly indicated. This is especially important for low head installations where the ' house loss ' may, through the use of valves, bends, and tees of smaller size than the external pipeline, be several times the ' mains ' friction.

Multiple Pumps

The requirements should also state, where parallel operation has to be provided, whether the calculations have been based on the maximum number of pumps in operation or on solo conditions (Figs. 6 and 7.) It should be made clear whether solo or parallel operation is the more important and whether the pumps are to be used in parallel only at the maximum

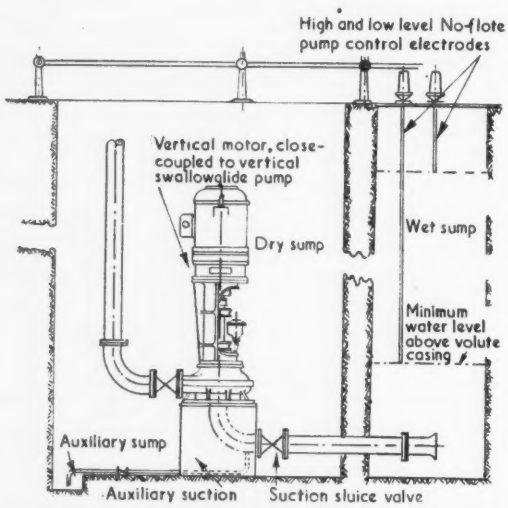

High and low level No-flote pump control electrodes
Vertical motor, close-coupled to vertical swallowglide pump
Dry sump
Wet sump
Minimum water level above volute casing
Auxiliary sump
Auxiliary suction
Suction sluice valve

Fig. 5—General arrangement of vertical Swallowglide pumpset in dry sump

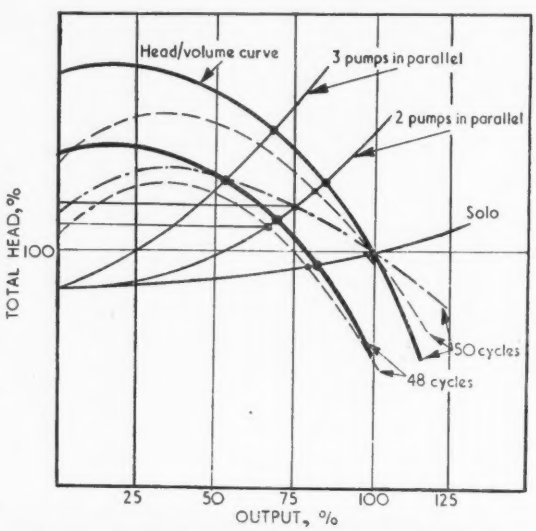


Fig. 6—Pumps in parallel on fixed-duty pipeline

capacity or whether load sharing is desired even with small flows as, for example, in boiler feeding.

When pumps are intended to share the load on a system where the demand varies considerably they are designed to have continuously falling head/volume curves to prevent pipeline surges, hunting between pumps at light loads, and water hammer.

Frequency Variation

During abnormal conditions of electricity supply it is necessary to consider what is the minimum capacity that can be accepted when the periodicity is at its lowest expected value. The closed valve head generated by each pump must not only exceed the static or residual head of the system but must also exceed the head in the system when all the other pumps on the pipeline are in operation ; *e.g.*, if three pumps are to be in parallel then the closed valve head of each must exceed the system head when two are in operation (Fig. 6). The full curves illustrate adequate characteristics for both full and reduced speeds. The broken curves are not very suitable for three-pump operation at 50 cycles and only good for solo or two-pump operation at 48 cycles, as the C.V. head at the latter speed falls below the system head with two pumps running. The third unit could not generate sufficient head to open its non-return valve against the downstream pressure. The chain-dotted curve illustrates a pump which, at the designed speed, could only operate up to a two-pump cycle because of its fall in C.V. head. When it is necessary to run more than one pump in parallel, the relative importance of the various combinations should be considered so that the condition applying to the greatest number of running hours is as efficient as possible. In general a three-pump operational system will be best met by a two-pump duty that is near maximum efficiency, with increased flow from one pump solo and with reduced outputs per pump when three are running.

Figures 8 and 9 illustrate the effects of frequency variation where the system is (*a*) 100% friction and (*b*) 95% static with only 5% friction. Intermediate cases will be clearly visualized. Overhead tank filling may readily result in case (*b*) and, unless care is taken, inadequate filling may occur during certain periods of the day.

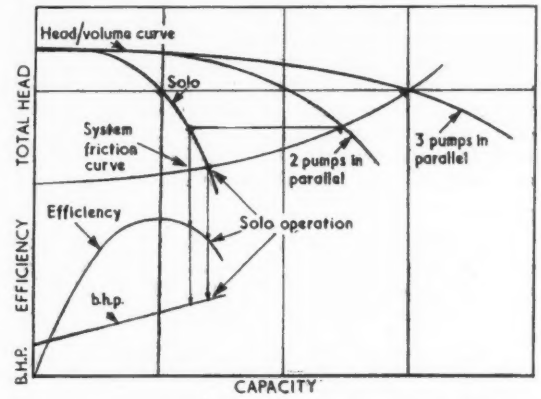


Fig. 7—Comparative performance for treble, twin, and solo operation. All pumps designed for treble-duty head

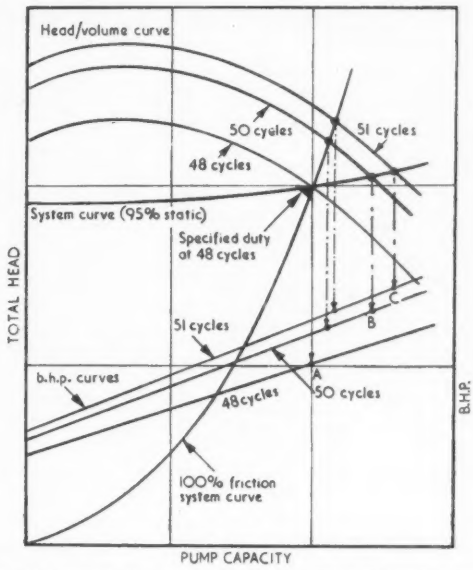


Fig. 8—Effect of speed increase on designed output and power

Quality of Water

The life of the plant and the amount of maintenance required will depend upon the correct choice of the type, design, and material construction for the quality of water to be pumped. It is important that both the chemical conditions and the possibility of suspended solids should be declared. Saline or brackish waters are best served by pumps manufactured from non-ferrous alloys. Where these are not available, or considered too costly, mixtures of bronze and iron

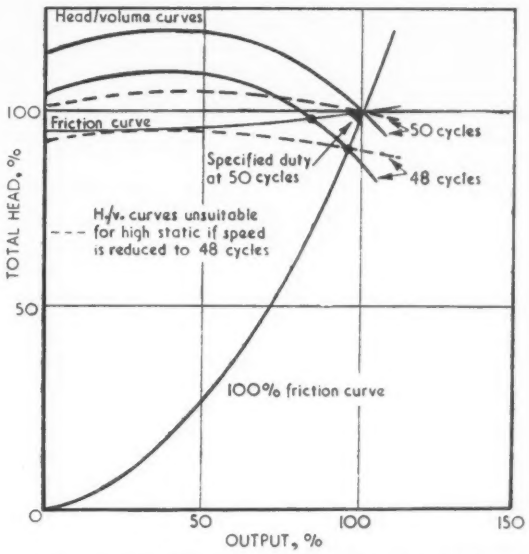


Fig. 9—Effect of reduced speed frequency on duty

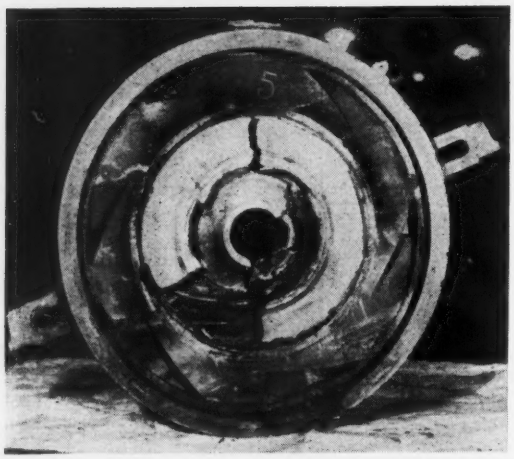


Fig. 10—Stage from vapour-locked pump illustrating effects of severe overheating and final seizure

should be avoided and an all-ferrous unit should be installed. Normal cast iron must not be used where the waters are lacking in oxygen and where free CO_2 is present as these are very liable to encourage graphitization. Non-ferrous metals and certain alloy irons are advantageous in handling such water.

Suspended abrasive matter will demand either a pump initially designed for this condition or one adapted from a clear-water type. If the solid content is high (as in scale-laden return water or blast-furnace gas-cleaning water) normal high-efficiency water pumps of orthodox design are not suitable, but units of special design and material are desirable. Adaptations of clear-water designs are possible where the solid particles are very fine, widely dispersed, and not highly abrasive, or where the pressure to be generated is such that multi-stage pumps are necessary. Depending on the type of liquid, either unchokeable or even lined slurry pumps may be necessary. Single, double, and multi-stage centrifugal pumps may have rubber-lined neck-rings and stage bushings incorporated, with the glands fed with clean water. Balance discs in such cases are relegated to pressure-reducing items for preserving the glands, whilst the actual thrust is transferred to a full-capacity thrust-bearing of the Michell type.

Filtration

To maintain pumping plant near its initial efficiency and capable of its designed duty it is necessary to prevent, as far as possible, undue wear at the points of fine clearance. Filtration and/or sedimentation should therefore be included in the layout if considerable silt or solid matter is likely to be present and the purpose of pumping is not the conveying of such solid matter. It is of particular importance in recirculation systems in a steelworks, where it is almost impossible to prevent the ingress of fine abrasive matter into such water systems, excluding those intended for the collection of such solid matter, *e.g.*, blast-furnace gas-cleaning systems.

Rotary screens with continuous jet cleaning can be employed at river intake stations to prevent the suction-pipe strainers or even pumps becoming clogged with vegetable matter. The area of the holes in the actual pipe inlet strainers should be at least $2\frac{1}{2}$ times that of the pipe. In internal circulatory systems such as descaling, etc., enclosed strainers may be employed in the suction system : it is wise to instal gauges (of simple pressure, vacuum, or differential pattern) at these strainer boxes so that fouling may be readily ascertained.

Where the recirculated water collects considerable solid matter of a fine nature, settlement chambers must be used ; their intake must be well removed from the suctions to the pumps and be of such a size that the rate of flow is low enough to allow maximum settlement. Such chambers or sumps should be provided with barriers so that the water has to flow up, and over, preferably two such baffles in series. The removal of the deposit at regular intervals can best be accomplished by a sludge pump of the unchokeable type, with flexible suction hose and auxiliary jets to break up and mix the banks of deposit into a liquid form. The floor can be cleaned while the sump is still in use if the operation is carried out frequently before the deposit coagulates and if the suction is designed on vacuum-cleaner-nozzle lines. Attention to adequate settlement sumps in the planning stage will be amply repaid in the reduction of pump outages, emergency breakdowns, and the cost of spares and renewals.

Allied to the material cleansing of recirculation systems is the advisability of keeping a check upon the departure of the water from a neutral state to one of acidity or chemical pollution. Where such deterioration is possible or is indicated by attack then the possibility of correction should be fully investigated.

Specific Gravity

A centrifugal pump will (ignoring viscosity) give a constant characteristic at any constant speed, *i.e.*, the volumetric output in gal./min. and the head in feet at any point on the characteristic will remain constant irrespective of sp. gr. changes. Reduction of sp. gr. will, however, reduce output if expressed in lb./hr. or will reduce pressure in lb./sq. in. The b.h.p. absorbed also varies, and in each case the variation is proportional to the sp. gr.

OUTPUT

There is still a considerable misunderstanding of the effect of working a centrifugal pump outside its designed duty range. Although it may be expected that a pump can operate from the closed-valve condition up to the specified gallonage it is not wise to make it work inside the lower half of this range for any length of time, for the following reasons.

No-Flow

Operation at no-flow for more than a few minutes is dangerous, as it causes temperature rise, vaporization and steam-logging of the unit, which will result in a complete or partial seizure of the pump (*see* Fig. 10).

A leak-off from the delivery branch will control the rise in temperature, and a leakage rate equal to a tenth of the motor rating will limit the total increase to approximately 20° F., which is usually a sufficient safeguard. This leak-off must either be taken to waste

or be returned to the suction system at a point far removed from the pump to ensure that the hot water is not merely recirculated with consequential progressive temperature rise.

Reduced Output

Operation at considerably reduced outputs has several deleterious effects : low-efficiency operation (*see*, for example, Fig. 11) ; increased turbulence with possible serious erosion in single volute casings ; and heavy radial thrust.

Turbulence—The liquid is circulated round the casing with considerable re-entry to the impeller passages between the vanes causing a heavy cavitation corrosion on the trailing face of the volute cutwater tip, particularly in corrosive waters. In the impeller handling abrasive liquids the trailing or underside faces of the blades suffer erosion. On open-sided impeller pumps the side plates suffer from advanced erosion on paths along the above re-entry lines.

Radial Thrust—In single volute casing pumps the radial thrust is substantially balanced at maximum efficiency operation but becomes unbalanced at an increasing rate as the output is reduced. This thrust acts towards the volute tip or throat and will account for the wear on necks and bushes *above* the centre-line in high-head-per-stage single volute pumps with upward discharges. An approximation of the thrust at closed valve is

$$\frac{0{\cdot}4}{2{\cdot}31}\left(\begin{array}{c}\text{impeller dia. (in.)} \times \text{impeller width at}\\ \text{periphery (in.)} \times \text{head (ft.)}\end{array}\right) \text{lb.}$$

This thrust bends the shaft unduly in a fixed direction causing full stress reversal at every revolution. In double-entry pumps such bending breaks down the joints between sleeves and impeller so that the water has access to the shaft at the point of maximum deflection. The consequent rings of corrosion localize and accelerate the fatigue. Sufficient enlargement of the shaft diameter is not possible because it would then encroach unduly on the impeller-eye waterways. Double volute casings partly relieve this thrust whilst diffuser or guide-port pumps reduce the danger to a minimum.

Methods of Adaption

It will thus be appreciated that if small quantities of water are required for a considerable time then the pumping plant should be designed accordingly.

A simple method is either to grade the unit sizes for progressive working or in some cases to employ three half-duty pumps instead of one full-duty unit and a standby. Alternatively, sufficient extra water may be by-passed to a suction reservoir. When considering the split up of the total output into part duty units, it should be known whether the smaller sets are expected to work in parallel or only to work solo in graded steps. In the latter case the pumps need be designed only for the head necessary to pass the reduced outputs, but in the former all units must be capable of the ultimate head with maximum flow. Where there is considerable friction the operation of one of these reduced-output, full-head sets under solo conditions will result in the delivery of a flow considerably greater than that specified, and consequently the motors must be increased in rating. Suction conditions must also be examined in relation to this increased flow as well as at the specified output (Figs. 7 and 1).

When there is a possibility of periodic closed-valve conditions (as in boiler feeding or descaling) adequate leak-off capacity can be provided *via* automatic leak-off non-return valves with which the closing of the non-return valve mechanically opens the by-pass and the opening closes the by-pass. This operation occurs *before* the main valve is fully seated so that there is *always* some flow through the pump. Such valves must be sited between the pump and any delivery control valve to provide full protection against closure. Temperature-operated by-passes are used in certain cases but the temperature-sensitive element should be mounted in the point in the pump where there is the highest possible temperature, *i.e.*, in the balance-water return or outlet pipe. Insertion of the element in the main delivery pipe adjacent to the delivery branch is not to be recommended in cases where the balance-water return pipe is available. Where the delivery branch is the only possible position a small permanent leak-off must be included beyond the temperature control point to ensure that some of the heated water will flow past the element. The thermal leak-off has a disadvantage relative to the A.L.O.N.R.V. in that it operates only *after* a temperature rise has occurred and can thus be considered curative rather than preventative, and the margin of safety is of necessity reduced. In systems employing accumulators either of the weight-loaded or air-bottle types the leak-off may be brought into operation by mechanical connections in the former or by control from pressure or level switches in the latter. In some cases a thermal control is used as a subsidiary or second line of protection on accumulator systems.

In small installations at low head a permanently open by-pass may not be too wasteful. It has the

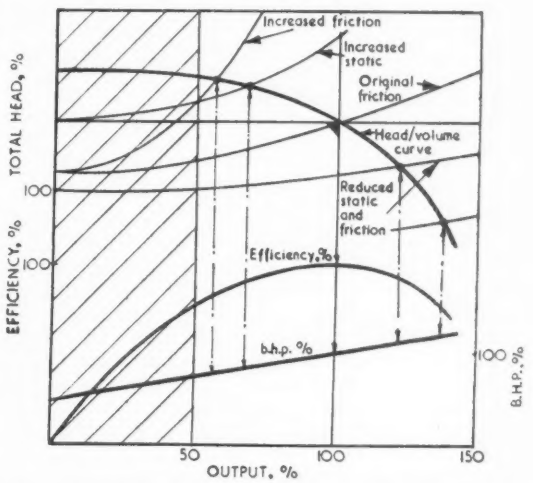


Fig. 11—Effects of system changes on pump performance. (Shading indicates area to be avoided on single volute pump because of high radial thrust)

advantage of simplicity and has no accessories to go out of order.

A Venturi meter or orifice plate may also be used to actuate the leak-off *via* relays. The by-pass will then come into operation at a predetermined minimum demand to avoid hunting.

It is essential, where electric contacts or relays are used, that the by-pass should open if the auxiliary current fails. This procedure covers the possibility of dirty contacts.

Since the by-pass water is led from the full delivery pressure to atmospheric or near-atmospheric conditions, a break-pressure orifice should preferably be incorporated following the actual by-pass valve in order to relieve it of erosion. This orifice will discharge a high-velocity jet into the following return piping and it is necessary on all high-pressure systems to employ a velocity-reducing vessel immediately following the orifice. This vessel should have a minimum size of approximately 6 in. dia. bore and 4 ft. 6 in. length. The break-pressure device should be incorporated either at the entrance to the cylinder (as a multi-hole orifice plate to reduce noise) or as three or more single-hole orifice plates in series spaced along the length of the cylinder. Single-hole single orifice plates at pressures of 800 lb./sq. in. and above are liable to cause a loud whistle or scream.

AUTOMATIC OPERATION

In a number of cases it is desired to introduce automatic operation, either for starting and stopping, or simply for stopping the units.

If the plant is to supply a tank or reservoir then float control from the delivery point is simple. Similarly if water disposal is the object then similar float control from the suction sump will be employed. An alternative to the suspended float is the electrical ' No-flote ' gear, which is operated by the fluctuating water level, alternately covering and uncovering the electrodes. All these methods require electrical connection from the tower or reservoir for delivery side control, which may be inconvenient. Alternatively, time control may be introduced for both starting and stopping, or it may be quite suitable to start either by hand or by clock and have some other form of automatic shut down, such as pressure switches, undercurrent release or paddle switches in the pipeline, to prevent overflow.

Pressure Switches

A centrifugal pump normally has a curve rising towards no-flow and by correct choice of frame and/or the fitting of suitable impellers a reasonably steep curve may be obtained whereby, as the flow is reduced towards zero, a pressure switch at the pump will shut down the motor by means of a float or ball valve closing at the tank. In order to prevent considerable operation while throttling as the valve closes with the rising water level, it is advisable to use a quick-acting float, which is out of circuit until the main top water level is approached. This requires an overflow into an auxiliary chamber and a small relieving non-return or float valve from the auxiliary chamber into the main reservoir. This system can also be adopted to start up the set at low level provided that there are no draw-offs from the pumping main *en route*. A small hydro-pneumatic vessel is then required to keep the main pressurized above the static while the pump is standing. When the float valve opens at the low level the pressure vessel discharges to the reservoir and thus its pressure falls to the static and the pressure switch starts the pump. When the reservoir is filled, the air content of the vessel is compressed by the pump working towards closed-valve conditions at an increased head, and the unit is cut out.

Undercurrent Release

In some cases where it is impracticable to provide a suitable pump-pressure/volume curve, advantage may be taken of the falling power curve towards closed valve and an undercurrent release used to cut out the set.

Paddle Switches

Paddle switches may also be inserted in the pipeline near the pump so that the set shuts down when the flow allows the paddle to take up a position of rest. To avoid the seizure of a gland on the swivel arm, recourse may be had to magnetic switches.

Safety Switches

In all cases of delivery side control it is advisable to have an overriding safety switch to cut out the set if the suction water falls to a dangerously low level. This will be a float or ' no-flote ' switch. Similarly, the sets should have a safety pressure switch on the delivery side to prevent the pump starting if it is not fully primed, *i.e.*, if the standing delivery pressure falls to a predetermined low value—say 10–20 feet. These two safeguards should also be employed in conjunction with remote push-button starting if there is a suction lift or danger of overdrawing the supply.

Hydro-Pneumatic Control

Overhead tanks in small and medium-sized units may be eliminated by a hydro-pneumatic system in which the reservoir is replaced by an air/water vessel downstream of the pump non-return valve. At periods of low demand the excess water is delivered to the vessel and the air pressure thus raised to cut-out value (slightly below the maximum pump-generated pressure). While the pump is standing the demand is supplied from the vessel, thus dropping the pressure to the cut-in value, usually the pressure equivalent on the pump curve to that at the maximum water demand. A compressor is necessary to replenish the air supply from time to time. During periods when the demand is between maximum and, say, 50% of maximum the pump will run continuously with the air vessel floating on the line.

PERFORMANCE AND MAINTENANCE

After plant has been correctly chosen and applied to the site condition it is important to keep the units up to specification as far as possible and to prevent deterioration. This includes a watch on additions to or modifications from the original plan. Sections of demand may be cut off or added. Tank positions may be altered and pipelines modified or become clogged with deposit.

INSTRUMENTATION AND CHARTS

So that those responsible for the satisfactory operation of pumping plant may have direct indication of changing conditions it is suggested that full instrumentation should be employed. This should include pressure gauges on the delivery and on the suction sides, an ammeter and a voltmeter at the pumping station to indicate any undue line voltage drops, and a means of measuring speeds whenever comparative data is being logged or if exceptional variation from the normal gauge reading is observed.

Flow meters should also be included on all the major units. Where it is possible to include them in some form, whether Venturi, orifice or rotary, a full check can be kept on all system alterations, *i.e.*, leakages, blockages, wear, etc.

It is a wise plan to have a performance chart for each pump unit installed, as knowledge of the particular characteristics will enable the operating engineer more readily to interpret any change in gauge or motor readings. Any proposed alterations to an installed system should be plotted against the pump characteristics to ensure that, in future, difficulties such as overloading of the motor or cavitation on the suction side are avoided. A reduction in the system head is not necessarily an easement of the pump duty, as will be observed from the pump curves in Figs. 1 and 11.

SYSTEM MODIFICATIONS

Should it be necessary to use a pump on a modified system, or to transfer it permanently to a system other than that for which it was designed, modifications that avoid inefficient operation may be possible.

Impeller Diameter

It is nearly always possible to reduce the impeller diameter to some extent so that the head generated at a given gallonage may more nearly equal that required. There will be a slight drop in efficiency owing to the altered impeller-blade proportions and the increased whirlpool area in the casing but this is much less than the loss by throttling on the delivery valve (*see* Fig. 12). Conversely, unless the maximum impeller diameter is already in use, an oversize impeller may be supplied to cover small increases in head. Such increase must of course be related to the possible motor output.

Dummy Stages

If the unit is a multi-stage pump then one or more stages may be removed and replaced by dummy stages in addition to, or in place of, impeller diameter adjustment. Where the multi-stage pump is of the cellular design it is possible to add a stage by the supply of a new shaft and binding bolts, plus pipe and bed modifications. The alteration in the number of stages where the unit under both conditions consists of four or more stages is immaterial as regards efficiency variation and can be ignored for all practical purposes.

Speed Variation

Speed variation may be usefully employed in many cases where constant speed does not cover the efficient or advisable operating ranges. If D.C. supply is available speed variation is simple and efficient, but

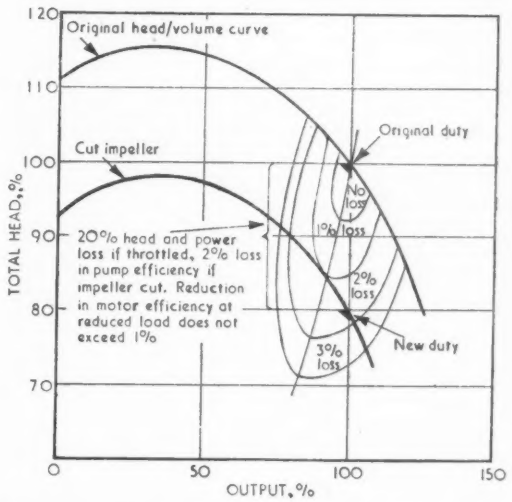


Fig. 12—Approximate indication of efficiency variation with impeller cuts. (For multi-stage diffuser pumps instead of 0%, 1%, 2%, and 3% read 1%, 2%, 4%, and 5% respectively)

in most cases nowadays A.C. supply only is available. The simplest method therefore is to use A.C. slip-ring machines with continuously rated rotor resistances. The speed of the machine may be reduced below its normal slip from synchronism but cannot be raised. Alternatively the more expensive A.C. commutator motor may be used, with which speeds may be varied both above and below the synchronous ; but for speed reduction up to 10%, or over a greater range so long as the major running hours are within 10%, the normal slip-ring motor will be found to have the better overall economy (including first cost and consumption figures). The loss caused by the rotor resistance is approximately proportional to the reduction in speed. Variable-speed couplings of the hydraulic or magnetic slip type can be used in combination with constant-speed motors but with these couplings, even at its maximum speed, the pump must lag behind the motor speed by approximately 3%, and this represents a power loss in addition to the windage factor and speed control losses. As a result of the compensating slight increase in pump size, multi-stage pumps may require an extra stage. On smaller pumps Texrope drives with a simple pulley change for permanent duty alteration that avoids interference with the pump proper may be used, but the accompanying belt loss has to be set against their flexibility.

INEFFICIENT PERFORMANCE

If a sufficient supply of water is not maintained at the delivery point at all times the pumping is inefficient. The fault may be in the pumping unit or in either the delivery or the suction side of the system. If the pump is at fault precautions must be taken to minimize outage time, and in all cases an attempt must be made to foresee possible breakdowns.

The regular use and logging of gauge and meter

readings will show up any abnormalities, thus providing time for analysis, and, in a number of cases, the correction of the initial fault before it has time to cause serious damage, or before the wear in a pump seriously affects the output. Thus a suitable opportunity can be taken to examine the unit instead of waiting for a failure during an operational period.

Checking

Where required, a check can be made on the static head on the delivery side immediately after a pumping run, by reading the delivery gauge with the by-pass open across the non-return valve and the sluice valve cracked open (if there is a foot valve). Alternatively, a gauge connected immediately above the main valves will provide the data at shut-down. The pump should always have been pumping immediately prior to the check to ensure a full pipeline.

Unless water meters are incorporated in the pipeline, or flume, tank, or weir measurement is provided at the delivery end, it is difficult to insert any measuring apparatus temporarily, that is not of a low-loss type, because the total head is increased by friction and hence output is reduced. If only a comparison at regular intervals and not an actual check on quantity is required, then a temporary meter might be installed as needed in pipelines of similar size. The easiest method would be to arrange lengths of parallel by-pass lines controlled by sluice valves (with one also in the main line) with a space for the meter and Johnson-type couplings. An alternative method of periodic quantity checking without permanent meters is to determine, by means of a notch, flume, or calibrated nozzle, the characteristics of the unit by throttling on a return line to the suction tank (from the delivery side). If nozzles are used then the tank must be so arranged that the aeration is removed before the water re-enters the suction pipe. (Alternatively the discharge could be temporarily taken to waste.)

With a sizeable suction tank it may be possible to isolate the intake for a period, either from the whole or a portion that can be sluiced off from the remainder, and then, with the pump on normal duty, to time a predetermined drop in the suction level, having previously calibrated the tank. The variation in suction level during this test must not be allowed to reach the cavitation figure nor must it fall low enough to permit air-drawing. The level should only differ by one foot from the normal level so that the total head is not materially affected (*i.e.* in low-head pumps).

Before comparing gauge heads with the pump curve, additions must be made for gauge heights and velocity-head differences between the points of measurement.

Whenever any electrical disconnection has been made it is essential to check the rotation when reconnection is made. No pump will develop the same characteristics in reverse but single volute pumps will deliver *some* water through the system and therefore the fault may not be immediately noticed. Multistage pumps of the diffuser type will not generate more than 50–60% of their normal head when running in reverse and consequently, except on low static installations, will not deliver any water, but on spray systems or other mainly frictional layouts they will operate at much reduced capacities.

Changes in Head

The flow-meter will immediately prove whether the correct and full quantity is passing through the pump or, where no water meter is installed, the gauges and electricity meters will supply the data for deductions to be made.

For the normal centrifugal pump an increase in the total head, as shown by the summation of the suction and delivery gauge readings, will indicate a reduction of output. A coincidental reduction of the current at constant voltage will confirm the above deductions and remove doubts of faulty gauges. Such an indication definitely points to throttling in the pipeline on the delivery side (Fig. 11).

A drop in total head with increase of the vacuum-gauge reading and reduced amps., indicates limitation by suction-side cavitation control, either by increased static lift or blockage in the pipe or strainer. Temporary throttling on the delivery valve should in this case reduce the capacity below that of the cavitation point and so restore the total head, thus proving the suction trouble (Fig. 1).

Should the vacuum and pressure readings both fall in addition to reduced amps. then one of two causes may be sought—(*a*) air leaks at joints or glands, or (*b*) blockage at the impeller eye, *i.e.*, beyond the vacuum gauge. If, on closing the delivery valve, the head gradually diminishes then the air intake is the fault.

A reduced total head with lowered delivery gauge but increased vacuum and increased amps. will indicate either (*a*) a considerable leak in the delivery line, or (*b*) wear in the pump clearances such that the impeller is maintaining its capacity but that an increased percentage is recirculating internally in the pump and a reduced amount is passing into the delivery system. Thus, while the impeller works outwards along its performance curve the pump as a useful unit is falling back along the friction curve towards no-flow conditions. Examination of the delivery pipeline will determine which symptom is applicable.

It should be remembered that at all times the point of operation *must* be that of the intersection of the head/volume characteristic and the system friction curve (Fig. 11). Therefore, an altered duty means that either the system friction curve has risen if the head is higher or that on lowered total head either the pump or friction curve has fallen bodily.

All the above comments are based upon constant speed and constant voltage. (If the voltage varies then current must be corrected approximately inversely to the voltage variation before employing the figure in the above deductions.)

If the speed is low then the reduced head and amps. readings should be corrected to the original performance curves on a common quantity line (not, however, to the original duty point unless the system is entirely frictional). (Fig. 9.)

Rising Current

Rising current with no other obvious change in readings indicates a mechanical fault and early investigation is demanded to prevent possible seizures.

Multi-stage pumps with balance discs should have the axial wear indicator regularly under observation. Numerous cases have occurred where such indications have not been noticed until the movement has been sufficient to close up the coupling gap and overheat or damage the motor bearings. By this time, also, serious wear will have taken place in the pump by the axial misalignment of impellers. The duty will also in most cases have been reduced by the internal throttling effect.

Any commencement of vibration or undue internal noise should be followed by an early investigation.

Glands should receive regular inspection and replacement of packing, noting that seepage should always be allowed otherwise dry abrasion will occur in the sleeve. Packing should never be unduly tightened.

Spares

To minimize the outage time an adequate supply of spares should be carried. These can consist either of normally consumable items such as neck-rings, bushes, sleeves, balance discs and plates, and bearings, or, alternatively, a complete rotating element (including the stationary wearing rings and bushes in contact therewith). Changing the whole element entails on the average the shortest time for reconditioning as any remachining of the old parts can be done at leisure after the unit is again at work, particularly in horizontally divided casing pumps where the old rotor can be lifted out complete and the new one dropped in place immediately. It is good practice to have the spare neck-rings and bushes of undersized bore to enable impellers, etc., to be skimmed up if worn. The ring bore can then be finished to give the correct clearance at the reduced diameter.

TYPES OF PUMP AVAILABLE

The main types of pump which will be found in a modern steelworks are as follows :

Single Impeller Pumps

These are divided into two main classes—those with horizontally divided casings, *i.e.*, split along the axis of the shaft, and those of end-cover design with the split perpendicular to the axis. Figure 13 shows a post-war introduction of medium- and large-size pumps directly connected to the motor without any intermediate coupling. Rigidity of alignment is thus obtained and shaft deflection at the gland and neck bushes is greatly reduced by the use of a much stiffer shaft than is otherwise possible. Gland-sleeve and neck-ring wear is also very much reduced, and installation space is saved, particularly in the vertical application, although the design is suitable for both horizontal and vertical application. Single-stage pumps are normally intended for low and medium heads with 300–400 ft. as the upper limit.

Two-Stage Pumps

Two-stage horizontally divided casing pumps normally have their impellers in series and in hydraulic opposition to avoid heavy end thrust. Volutes are staggered to avoid radial thrust.

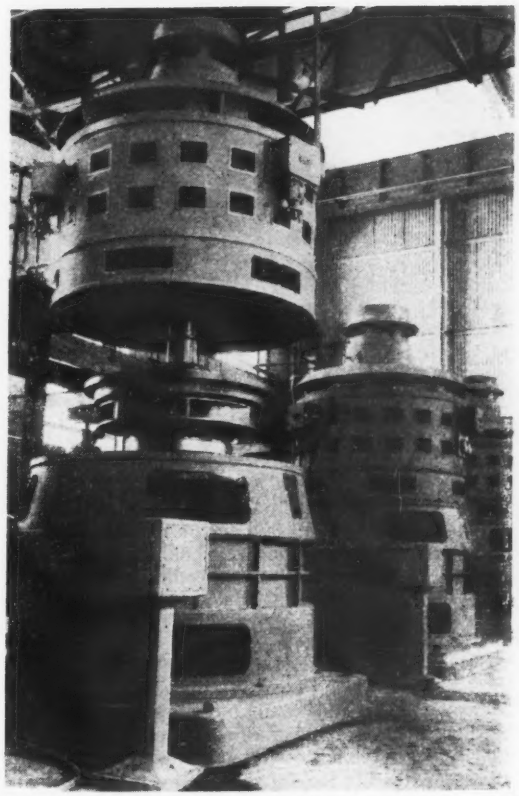


Fig. 13—Vertical ' unit construction ' pumpsets with stainless clad casings (18,500 gal./min., 145 ft. head, 495 r.p.m., 1050 b.h.p. motors)

Multi-Stage Pumps

In Britain multi-stage pumps that have three or more stages working in series for medium and high heads nearly always have the stages in direct series, ' line ahead,' with single-entry impellers incorporated. The stages are usually bolted together in a cellular construction.

The multi-stage horizontally divided casing pump is not generally favoured in Britain because of the difficulties of irregularly shaped joints, the difficulty of accurately matching all waterways, and the relative lack of flexibility, a different casing being required for each assembly of a different number of stages.

Total end thrust from the impellers is normally countered by a hydraulic balance disc. This balancing device also ensures that the delivery-end gland is at atmospheric or suction pressure and thus avoids the use of high-pressure glands. These pumps are applicable for all medium- and high-pressure duties, *viz.*, service water, scrubber and descaling jets, fire duties, hydraulic services, etc. If the water is continuously recirculated—even when straining and settlement are carried out—or if frequent starting and stopping is desired, it is advantageous to fit a Michell thrust-bearing, in addition to the hydraulic balancing device, to prevent the high percentage of fine grit wearing the faces and causing axial movement of the rotor. Most of the wear on the disc will take place during the

Fig. 14—Battery of vertical submerged service and drainage pumpsets

first few revolutions when the liquid film is not properly established. Thus, the thrust-bearing should be set to carry the load with the balance disc face about $\frac{5}{1000}$ in. away from the stationary plate. If the water leaves a film or scale on the metal surfaces the stem clearance leading to the balance disc must be increased to ensure adequate feeding of the balance faces.

Slurry Pumps

Single-stage unchokeable or slurry-type pumps for the handling of solid-bearing waters may be designed to pass considerable amounts of sizeable solids or may be specially built of abrasion-resisting materials, *e.g.*, with an inner casing of manganese steel and an outer readily machinable casing. Rubber-lined pumps are also employed to handle solid-bearing liquids where heavy abrasion is expected. It is advisable to have a supply of clean water fed to the glands of all dirty-liquid pumps even in designs where the solids are pumped away from the stuffing box. Foot valves are liable to clog or jam and it is preferable to have a flooded suction (certainly where automatic operation is desired) or else to prime by evacuation (Fig. 5).

Suspended Pumps

Suspended or borehole-type pumps are imperative

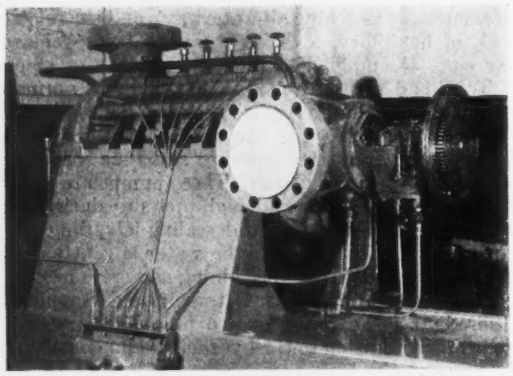


Fig. 15—Boiler feed pump (620,000 lb./hr., 1200 lb./sq. in., 2970 r.p.m.)

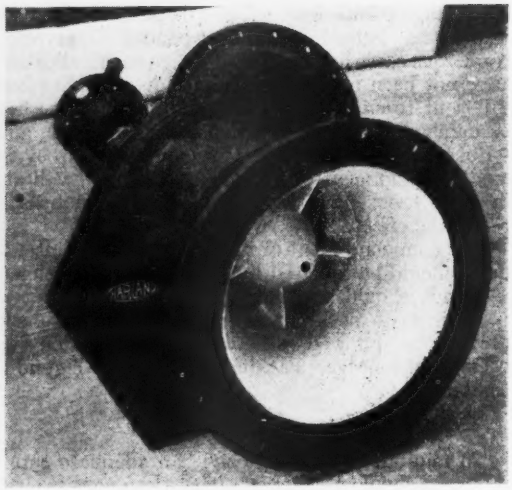


Fig. 16—Axial flow pump arranged for insertion in pipeline

if the service water supply is from an underground source, and they save considerable floor space and overcome all priming difficulties if it is from a culvert or channel. Intermediate bearings may be either water-lubricated or fed with grease from a mechanical lubricator mounted at the headgear (Fig. 14).

Boiler Feed Pumps

These embody the features of the multi-stage pump range together with water cooling of the glands and bearings, and with centre-line support at the elevated temperatures on all but the smallest sizes. Head/volume curves continuously falling from closed valve are provided for proportional load sharing (Fig. 15).

Boiler Circulating Pumps

Boiler circulating pumps for forced-flow boilers operate at the boiler pressure and temperature although only generating the low head represented by the boiler-tube resistance loss. They are simple single-stage pumps in effect but with high-pressure bodies and glands. Specially designed long stuffing boxes intimately cooled are required, together with water-cooled bearings.

Propeller Pumps

Propeller or axial flow pumps are used for handling large quantities of water—mostly drainage—at heads normally below 20 ft. They may be vertically suspended in a culvert as shown in Fig. 14 or may be inserted in an angle or slope of the pipelines (Fig. 16).

APPENDIX

Spraying Installations *By P. L. Fairfield*

The many spraying applications in steelworks vary from special nozzles with high-pressure water to low-pressure gravity-fed holes in pipes. The most complex and exacting duty for pumps employed on this type of work is for supplying water to descaling nozzles.

Mr. Fairfield is in charge of the descaling department of the Harland Engineering Co., Ltd. at Manchester.

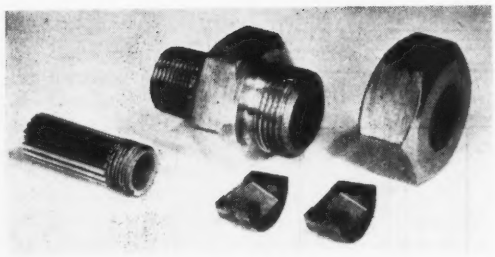


Fig. 17—Descaling nozzle

DESCALING

Application

Scale removal has been practised for many years by casting brushwood, rock salt, bracken, or even bucketfuls of cold water, on to the steel during processing ; by squeezing, rough rolling, or by using chain flails. The uniformity, efficiency, ease of handling and relative cleanliness of hydraulic descaling has now made it the accepted practice on most new installations.

A jet of high-pressure water travelling at high velocity impinges on to the surface of the hot steel and removes the scale by means of its impinging force, by its chilling effect that causes cracking, and by penetrating the relatively porous scale and then expanding and causing local explosions that effect the removal. The water must be directed carefully, in sufficient quantity, and with sufficient velocity. Where possible the nozzles are used after a mechanical scale breaker but quite remarkable results have been obtained by descaling immediately the product leaves the furnace.

The most satisfactory nozzle orifices vary from $\frac{1}{64}$ sq. in. to $\frac{1}{32}$ sq. in. ; smaller orifices are liable to blockage and larger ones cause unnecessary cooling. The working pressures corresponding to these orifices and to a satisfactory velocity jet vary from about 900 lb./sq. in. to 1500 lb./sq. in.

Type of Nozzle

To cover large areas with high-pressure water the material must move relative to the jet. It is simplest and most usual to move the material, although movement of the jet has been applied with some success.

To conserve hydraulic power and cause the least chilling it is advisable to use nozzles emitting a jet like a ' fish-tail.' Several such nozzles effect complete coverage across the material, with an impinging force of from 7·5–11 lb. per lineal inch of surface width, and result in water consumptions from 3–7 gal./min. per lineal inch.

With several nozzles located for simultaneous operation the absorbed hydraulic power is considerable. It is therefore essential that the nozzle itself should be as efficient as possible. The orifice has to withstand high flow velocities, and has therefore to be erosive resistant. A nozzle has been designed especially for this duty (Fig. 17), and gives an overall hydraulic efficiency of up to 96%. The disc comprising the orifice is formed in two halves and located within the nozzle cap in a self-locking taper. Manufacture in two halves permits grinding of the orifice throat before hardening and enables the hardened discs to be rectified if necessary after testing. A milled grooved strainer of phosphor bronze screws into the body, which is itself threaded with a $\frac{3}{4}$-in. dia. taper thread.

Design and Location of Headers

The location of the nozzles and headers in continuous mills used for strip, sheets, plates, and bars is not difficult as the mill housings can usually accommodate a header pipe supporting the required number

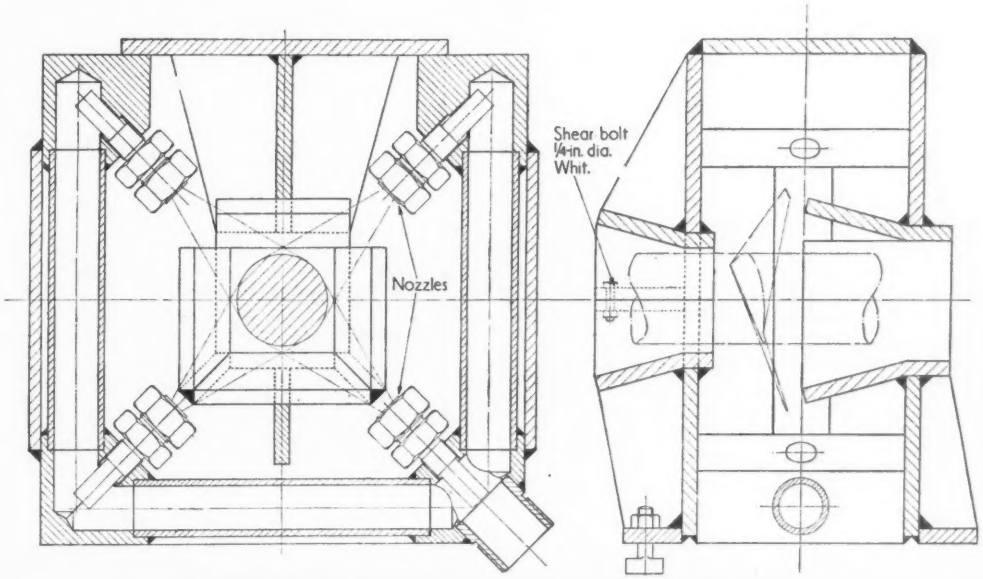


Fig. 18—Arrangement of descaling headers with 4 nozzles

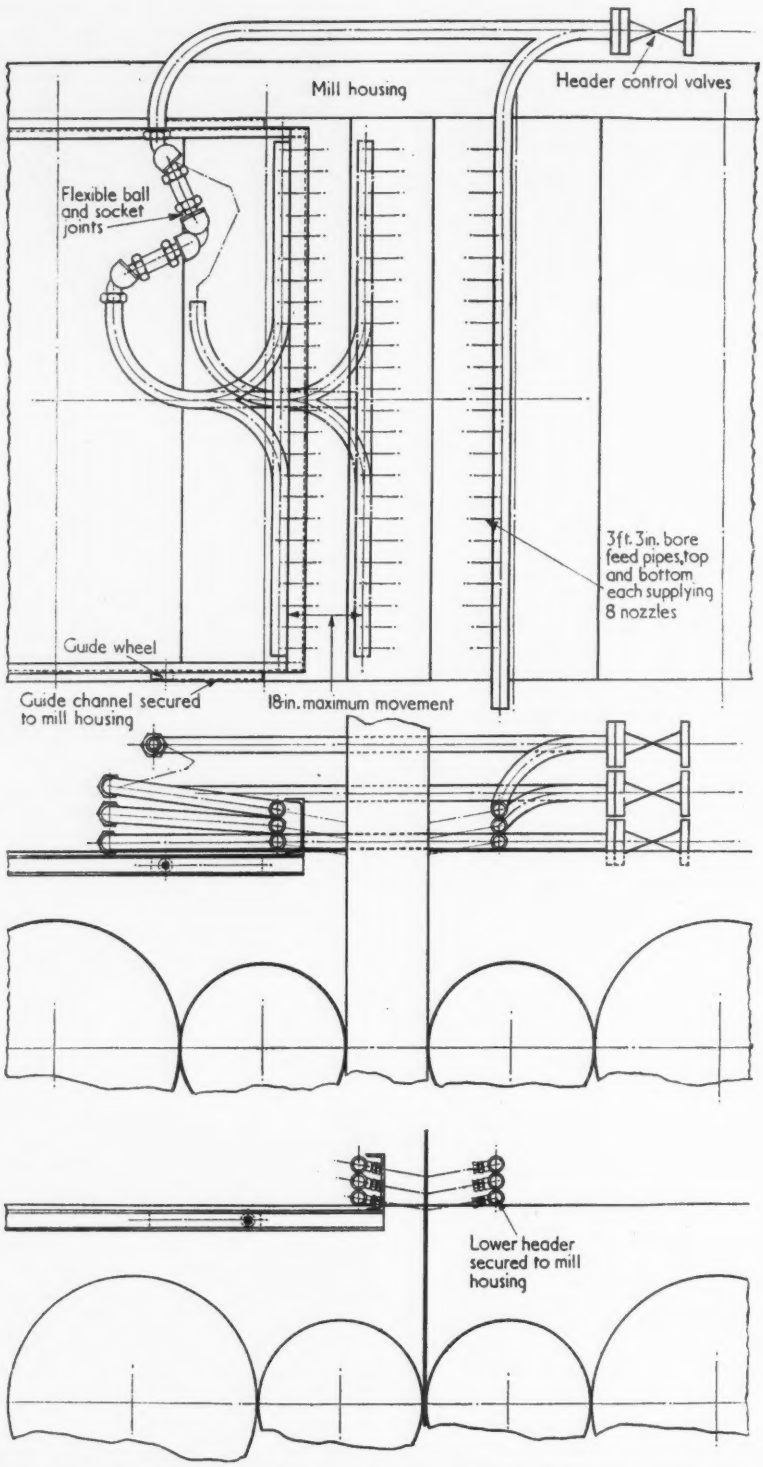

Mill housing
Header control valves
Flexible ball and socket joints
3ft. 3in. bore feed pipes, top and bottom each supplying 8 nozzles
Guide wheel
Guide channel secured to mill housing
18in. maximum movement
Lower header secured to mill housing

Fig. 19—Arrangement of descaling headers for 110-in. plate mills

of nozzles. On a modern high-speed strip mill there would be as many as five descaling headers but this may depend on the speed of the mill and the nature of the material.

On bar and section mills a variety of material sizes often have to be considered and this requires accurate positioning of the nozzles (Fig. 18). It may be necessary to change the headers when the rolls are changed if extreme material sizes are to be processed.

Reversing plate mills cause greater problems. It is normal to place the nozzles 10–12 in. from the surface to be descaled, and on mills that accommodate plates of widely varying thicknesses this will necessitate moving the nozzles during processing (Fig. 19). The headers are bracketed to the beam positioning the moving rolls and the nozzles fed through flexible joints. Separate valves permit the use of either 8, 16, or 24 nozzles according to the plate width.

Control of Sprays

When the operating cycle permits, the headers can be under the control of individual valves designed for rapid operation. A normal hydraulic valve is designed for 5000 operations per year, whereas those needed for descaling may require 100 times as many operations and so must be specially designed to withstand the working pressure and frequency of operation. They must be quick-acting if water is not to be wasted and yet they must not subject the system to an excessive shock loading.

Suitable valves are manufactured in the U.S.A. but no comparable equipment is supplied in this country, especially in large sizes. They are usually machined from the solid or made from forged or cast steel. They have either bleed-off holes or operating cylinders to control the rate of operation.

Piping System

With varying duty cycles, high pressures and velocities, and the need for reliability on descaling, the importance of low-velocity pipework systems cannot be over-emphasized. The duty is arduous for any pump and if high velocities are permitted, the possible shock loading transmitted to the pumps can be serious. Sharp bends, severe tapers, numerous junctions, and so on, should be avoided, and the general aim should be to keep flow velocities down to 8 or 9 ft./sec.

Type of Pump

Descaling systems require a relatively small quantity of water delivered at high pressure. The smaller schemes require the same pressure but even less water and for these a displacement pump is more suitable, particularly when a water reservoir is included to average the peak demands.

A ram pump is usually more efficient than a small centrifugal, but the initial cost and maintenance charges are greater, and the valves are more complex. Consequently there are very few instances when ram pumps have been chosen.

Features of Centrifugal Pumps

When hydraulic descaling was first introduced into this country in 1935, normal-type centrifugal pumps were installed, and one is still employed at a mill in South Wales. It was found, however, that the arduous operating conditions called for special features, which are included on the later pumps.

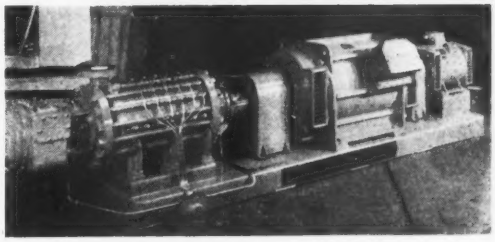


Fig. 20—Two-speed hydraulic or descaling unit (500 gal./min., 1000 lb./sq. in.; 515 b.h.p., 2870 r.p.m. 'Duty Motor' and 35 b.h.p., 960 r.p.m. 'Idling Motor')

The operating characteristic of a centrifugal pump follows a hump-backed curve and the selected duty point is usually well beyond the hump. It was found, however, that hunting about similar pressure points on either side of the hump could occur from the shock loading of valves, variable flow, and other factors. This difficulty has been overcome by the inclusion of special impellers that give a continuously falling characteristic.

The balance disc feature maintaining axial 'float' is subject to wear with sudden and reverse load changes, particularly when gritty water is handled. A Michell bearing carrying the full thrust is now an additional feature.

Mechanical strengthening, including the stiffening of the shaft and the use of special chambers and end covers, is now standard practice.

Accumulators

The inclusion in the system of an accumulator for averaging peak demands, although expensive, has many advantages, the most important being the prevention of water-hammer. Many large installations incorporate an accumulator solely for this purpose even when the pumping capacity is sufficient to satisfy a direct feed.

Power saving can be obtained by using large accumulator systems to average the peak demands on an intermittent duty system. A large plate mill may require 25 nozzles located above and below the plate, with a consequent high rate of demand, but it may only be necessary to descale on, say, one third of the total number of passes, so that the average demand is considerably less. For example, peak demands of 1700 gal./min. with an average of 600 gal./min. often arise and to satisfy such a peak demand without an accumulator would require a pump capable of 1,700 gal./min. with which it would not be possible to stop the set between each demand.

Other power-saving refinements can be incorporated such as electrical contacts mounted on the side of the bottle that effect speed control of the pump motor as the water level in the bottle rises and falls according to the demand.

An interesting application was supplied recently for steel cradle tilting; similar units have also been

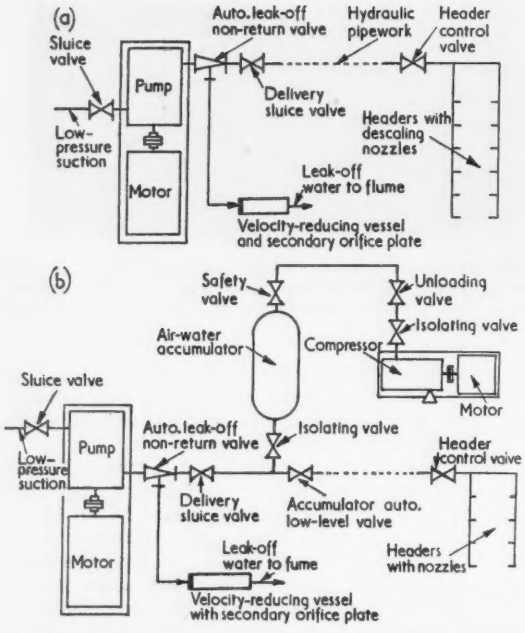


Fig. 21—Schematic arrangement of descaling equipment: (*a*) Direct feed system; (*b*) air-hydraulic accumulator system

considered for descaling systems. Water was demanded at a rate of 500 gal./min. and a pressure of 1000 lb./sq. in. for a period of two minutes, followed by no demand for eight minutes, in a continuously repeating cycle. A large reciprocating pump could have been used, with unloading valves to reduce the power consumption during the idle period. The difficulties entailed in the design of such valves and the economics of the comparative systems resulted in the following two-motor scheme being adopted.

A low-speed pony motor of 35 h.p. was mechanically coupled to the shaft of a 600-h.p. high-speed main motor driving the pump (Fig. 20). When the set was on duty the small motor was driven by the main unit but when the demand was reduced the main motor was isolated and the small motor connected so that the unit continued to rotate at one third of duty speed. This slower rotation, for which the 35-h.p. motor was sufficient, made rapid acceleration to duty speed possible without heavy electrical stresses, when the water demand was again required. Figure 20 also shows the Michell bearing.

Schematic Layouts

A direct feed system of a pump supplying nozzles is shown in Fig. 21*a*. The non-return valve incorporates a mechanical slide-valve feature which acts as a by-pass to ensure that the churned water does not boil within the pump when the demand at the nozzles is stopped. The hydraulic energy from this by-pass is dissipated across an orifice delivering either into a velocity-reducing chamber or to the scale

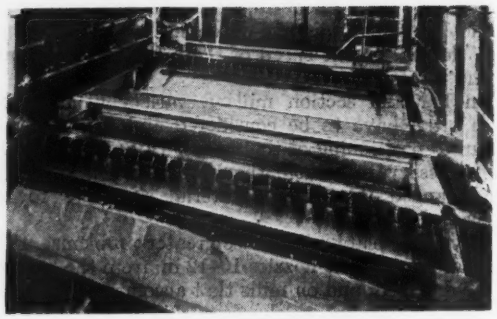


Fig. 22—Low-pressure ' fish-tail ' nozzles in operation at 45 lb./sq. in.

flume. A positive suction pressure is recommended to minimize the possibility of starving the pump.

A system incorporating an accumulator is shown in Fig. 21*b*. Electrical contacts on the bottle could be used to effect motor-speed control, to operate high and low safety valves, and to control light indicators.

LOW-PRESSURE SPRAYS

Other types of spraying installation now used in steelworks are carefully positioned cooling and washing sprays.

Earlier practice for most of these applications was to use a simple bus-pipe in which holes were drilled. The drilling burr was liable to cause blockage with foreign matter and the whole arrangement was inefficient and extravagant. Several types of nozzle are now marketed for these duties (Fig. 22). The jet emitted is again like a ' fish-tail ' thus ensuring the maximum coverage across a surface, but the spray form is obtained by using a round orifice combined with a curved deflector. Blocking on the smaller sizes is thus greatly reduced when compared with rectangular or elliptical orifices of similar area. These nozzles are all precision-finished in stainless steel, and are suitable for a variety of duties with clean or contaminated water.

Application

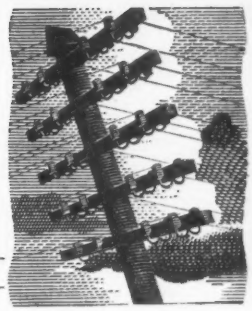
The method of application depends on the purpose for which they are employed but a header pipe supporting several nozzles arranged to give a curtain of water is the accepted practice. Valve control is necessary although the robustness of the installation is not as important as on a descaling installation.

The nozzles are particularly suited for use with water that has fine solids in suspension. For certain cooling and washing processes where the application of water with solids in suspension is permissible, recirculation of the mill water is possible. A special pump design and a slurry-type unit are necessary but the water-saving can be considerable.

Acknowledgments

The authors thank the Directors of the Harland Engineering Co. Ltd., for permission to publish the information and drawings given in this paper.

N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Annual General Meeting, 1952

The Annual General Meeting of the Institute will be held on **Wednesday and Thursday, 30th April and 1st May, 1952.** The programme is as follows:

Wednesday, 30th April

Morning Session

At the Royal Institution, Albemarle Street, W.1

9.45–10.30 A.M.—Formal business, including:
Report of Council and Accounts for 1951
Presentation of Bessemer Medal
Presentation of other Medals and Prizes

10.30–11.30 A.M.—
Induction of new President
Vote of thanks to retiring President
Presidential Address

(11.30–11.45 A.M.—Interval)

11.45 A.M.–1.0 P.M.—Sixth Hatfield Memorial Lecture on "The Flow of Metals," by Professor E. N. da C. Andrade, F.R.S.

1.0–2.30 P.M.—Buffet luncheon at 4 Grosvenor Gardens, S.W.1. Buses will be available to take Members from the Royal Institution.

Afternoon Session

At the offices of the Institute, 4 Grosvenor Gardens, S.W.1

2.30–4.0 P.M.—Joint Discussion on:
"*Cold Rolling with Strip Tension. Part I—A New Approximate Method of Calculation and a Comparison with other Methods*," by H. Ford, F. Ellis, and D. R. Bland (*May*, 1951)
"*Effect of Tension on Torque and Roll Force in Cold Strip Rolling*," by W. C. F. Hessenberg and R. B. Sims (*June*, 1951)
"*Pressure Distribution Between Stock and Rolls in Hot and Cold Flat Rolling*," by C. L. Smith, F. H. Scott, and W. Sylwestrowicz (*April*, 1952)

4.0–4.45 P.M.—Discussion on:
"*Softening of Metals During Cold Working*," by N. H. Polakowski (*Dec.*, 1951)

Evening

7.0 for 7.30 P.M.—Members' Dinner at Grosvenor House, Park Lane, London, W.1 (Tickets 30*s.*)

Thursday, 1st May

Morning Session

At the offices of the Institute

10.0–11.30 A.M.—Joint Discussion on:
"*An Experimental Furnace for the Investigation of O.H. Furnace Combustion Problems*":
"*Part V—Experiments with the Venturi Port and Modifications Thereof*," by J. F. Allen
"*Part VI—Summary of Results and their Application in Practice*," by J. R. Hall and A. H. Leckie (*Jan.*, 1952)

(11.30–11.45 A.M.—Interval)

11.45 A.M.–1.0 P.M.—Joint Discussion on:
"*Measurement of Air Infiltration in Open-Hearth Furnaces*," by R. Haynes (*Feb.*, 1952)
"*Aerodynamic Factors Associated with the Wear of O.H. Furnace Roofs*," by J. A. Leys and E. T. Leigh (*April*, 1952)

1.0–2.15 P.M.—Buffet luncheon at 4 Grosvenor Gardens, S.W.1

Afternoon Session

At the offices of the Institute

2.15–4.0 P.M.—Joint Discussion on:
"*Determination of Hydrogen in Liquid Steel*," by R. M. Cook and J. D. Hobson (*Sept.*, 1951)
"*Diffusion of Hydrogen in Iron and Iron Alloys at Elevated Temperatures*," by P. L. Chang and W. D. G. Bennett (*March*, 1952)
"*Distribution of Hydrogen in Large Ingots and Forgings*," by J. D. Hobson and C. Sykes (*Feb.*, 1952)
"*Effect of Hydrogen on the Properties of Low-Alloy Steels*," by J. D. Hobson and C. Sykes (*Nov.*, 1951)

Awards

Bessemer Medal

The Bessemer Medal for 1952 has been awarded to Mr. **H. H. Burton,** C.B.E., Vice-President (English Steel Corporation, Ltd., Sheffield), for his distinguished services to the steel industry and metallurgy, with particular reference to the development of alloy steels and of heavy forgings.

A portrait and brief biography of Mr. Burton appear as the frontispiece to this issue.

Sir Robert Hadfield Medal

The Sir Robert Hadfield Medal for 1952 has been awarded to Dr. **L. Reeve**, Chief Metallurgist to the Appleby-Frodingham Steel Co., in recognition of his contributions to the science and practice of ferrous metallurgy and, in particular, his researches on the weldability of low-alloy steels.

Andrew Carnegie Medal

No award has been made for 1951.

Williams Prize

The Williams Prize for 1951 has been awarded jointly to Mr. **J. A. Bond**, Blast-Furnace Manager at the Appleby-Frodingham Steel Co., and to Mr. **T. Sanderson**, Technical Assistant to the General Works Manager, the Workington Iron and Steel Co., for their paper "*Full-Scale Blast-*

Furnace Trials," published in the May 1951 issue of the *Journal*.

Ablett Prize

No award has been made for 1951.

Changes on Council

The following changes are announced:

Mr. W. B. BAXTER, C.B.E., has been nominated an Honorary Vice-President

Sir CHARLES BRUCE-GARDNER, Bt., has been nominated a Vice-President

Mr. E. J. PODE has been elected a Member of Council.

NEWS OF MEMBERS

▶ Mr. J. SIDNEY HAMPTON, Director of Davy and United Roll Foundry, Ltd., Billingham, Co. Durham, has been appointed General Manager of the Company.

▶ Mr. A. VON HEIJNE has left Söderfors Bruk to join Stora Kopparbergs Bergslags Aktiebolag, Falun, Sweden.

▶ Mr. J. E. HILLIARD has been awarded the Ph.D. degree of the University of Liverpool.

▶ Dr. AXEL HULTGREN has retired from his position as Professor of Metallurgy at the Royal Institute of Technology, Valhallavägen, Sweden.

▶ Mr. J. W. LENNOX, General Manager of Sintered Products, Ltd., a subsidiary of Sheepbridge Engineering, Ltd., has been appointed Director of the Company.

▶ Mr. E. W. MULCAHY has resigned his appointment with Messrs. John Thompson (Dudley) Ltd., and has formed his own Company, the Chemical Engineering Construction Co. (Consultants and Contractors), at Brierley Hill, Staffs.

▶ Mr. AXEL E. NYGREN has received the degree of M.Sc. in Metallurgy at Massachusetts Institute of Technology. He is now at the Uddeholm Co., Munkfors, Sweden.

▶ Mr. F. J. SKINNER has retired from Messrs. Joseph Stephenson and Co. (London), Ltd.

▶ Dr. C. J. SMITHELLS, Director of Research of the British Aluminium Co., Ltd., has been elected President of the Institute of Metals for the year 1952–53.

▶ Mr. C. B. SNODGRASS has been appointed General Manager of Fusarc, Ltd., and has relinquished his post as Works Manager of their Associated Company, the Quasi-Arc Co., Ltd.

Obituary

Mr. W. J. BROOKE, formerly Managing Director of John Lysaght's Scunthorpe Works, Ltd., and an Honorary Vice-President of the Institute, on 24th February, 1952.

Mr. O. H. GELLNER, of the Nuffield Research Group in Extraction Metallurgy, Royal School of Mines, in January, 1952.

Herr MAX HEUSSER, Director of Gebrüder Sulzer A.G., on 13th January, 1952.

Mr. E. W. T. REES, Chairman of D. Morgan Rees and Sons, Ltd., Cardiff, on 23rd July, 1951.

M. ANDRÉ VICAIRE, Managing Director of Entreprises Schneider, France, on 28th January, 1952.

CONTRIBUTORS TO THE JOURNAL

M. M. Hallett, M.Sc.—Chief Metallurgist of Sheepbridge Engineering, Ltd., Chesterfield. Mr. Hallett was educated at King's School, Worcester, and at University College, Cardiff, where he graduated with the degree of B.Sc. (Metallurgy) in 1931; he obtained his M.Sc. degree in 1939. From 1931 to 1943 he was employed in the research laboratory of The Mond Nickel Company, Ltd., Birmingham, specializing in alloy cast-irons, heat-resisting alloys, and alloy steels. He joined the Sheepbridge Stokes Centrifugal Castings Co., Ltd., as Chief Metallurgist in 1943, and remained there until taking up his present appointment.

Mr. Hallett serves on the Committees of the British Cast Iron Research Association and the Institute of British Foundrymen.

J. A. Cameron, B.Sc.—A member of the staff of the Brown-Firth Research Laboratories. Mr. Cameron was born at Coatbridge, Lanarkshire, and was educated at Coatbridge Secondary School and at the Royal Technical College, Glasgow, and at Glasgow University, where he graduated in 1945. He then joined the Metallurgical Research Department of Magnesium Elektron, Ltd., and in 1947 took up his present appointment. He is a member of the Isothermal Transformations and Hardenability Group of the British Iron and Steel Research Association.

E. O. Hall, M.Sc., Ph.D.—Lecturer in Physics at the University of Sheffield. Dr. Hall was born in 1925 in New Zealand, and received part of his education at Victoria University College, Wellington, where he was awarded the M.Sc. degree with 1st class honours in Physics. In 1948 he came to England as the holder of an 1851 Exhibition Scholarship and the Lord Rutherford Memorial Fellowship, and he joined the Metal Physics Group at the Cavendish Laboratory, Cambridge. Under Dr. E. Orowan, F.R.S., he studied the yield phenomenon in mild steel. After being awarded a Ph.D. degree he continued research in this field for the British Iron and Steel Research Association, and subsequently was associated with Dr. C. F. Tipper on fundamental problems in fracture. He took up his present appointment at the beginning of this month.

C. G. Evans—Chief Hydraulic Applications Engineer of the Harland Engineering Co., Ltd., Alloa. Mr. Evans received his early training with the Rees Roturbo Manufacturing Co., Ltd., Wolverhampton, where he worked mainly on centrifugal pumps. He spent a short period in the Turbine Drawing Office of the British Thomson-Houston Co., Rugby, before entering the Hydraulic Design Department of his present firm in the late 1920's. During the war he was in charge of pump design and application, and later, when these services were reorganized, he was appointed in charge of the Engineering Service Department.

IRON AND STEEL ENGINEERS GROUP

Meeting of Junior Engineers, 1952

A Meeting of Junior Engineers will be held at Ashorne Hill, Leamington Spa, on **Monday, Tuesday, and Wednesday, 19th, 20th, and 21st May, 1952.** Mr. C. H. T. Williams, Chairman of the Iron and Steel Engineers Group, will be in the Chair.

The object of this meeting is to provide an opportunity for the younger engineers in the iron and steel and associated industries to discuss engineering problems

of interest. Any member of these industries, under the age of 35, will be welcome at the meeting.

Four papers will be presented :

"*The Rehabilitation of a Slab Mill*," based on experiences at Cargo Fleet Iron Co., Ltd.

"*Experiences as Lubrication Engineer in an Iron and Steel Works*," by P. W. Murray, Colvilles Ltd.

"*The Use of Lubricants in the Iron and Steel Industry*," by H. J. Knight, Shell-Mex and B.P., Ltd.

"*Locomotives in Iron and Steel Works*," by G. K. Tatterson and R. L. Crook, John Summers and Sons, Ltd.

A selection of films, provided by Shell-Mex and B.P., Ltd., will also be shown during the Meeting.

A circular will be sent shortly to all Members of the Iron and Steel Engineers Group. It is hoped that firms will encourage their staff to attend the Meeting.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Zinc-Rich Paints

The Corrosion Committee of the Association has issued the following statement about zinc-rich paints :

"The use of the term 'zinc-rich paint' should be restricted to paints containing a sufficiently high percentage of zinc pigment to ensure direct electronic contact between the metallic particles in the dry paint film. There are theoretical reasons for believing that in the simplest case this will not occur unless the metallic zinc constitutes 92–95% by weight of the dried paint film—the exact value depending on the specific gravity and other properties of the vehicle."

The Corrosion Committee sponsored the work at the Cambridge University Metallurgical Laboratories which, during the early years of the last war, led Dr. Evans and Dr. Mayne to establish the usefulness of such paints in resisting corrosion, and the form in which they can be most effective. Zinc-rich paints are now finding numerous domestic and industrial applications.

INSTITUTION OF METALLURGISTS

Examinations, 1952

The next examinations for the Licentiateship and Associateship of the Institution of Metallurgists will be held from 25th August to 2nd September, 1952. Candidates must submit their applications for permission to enter the examinations before 1st May, 1952. Each application must be made on a form to be obtained from the Registrar-Secretary, The Institution of Metallurgists, 4 Grosvenor Gardens, London, S.W.1, and must be accompanied by a registration fee of one guinea. The balance of the examination fee will be payable before 1st August, 1952.

Examinations for the Fellowship will also be held between 25th August and 2nd September, 1952 (during August for overseas candidates). Intending candidates should apply for permission to enter the examination, submitting, for the approval of the Council, a statement of the branch of metallurgy in which they offer themselves for examination.

Examination fees, including the registration fee are as follows :

	£	s.	d.
Licentiateship examination	3	3	0
Associateship examination—			
Licentiates	3	3	0
Other candidates	5	5	0
Fellowship examination—			
Associates	5	5	0
Other candidates	10	10	0

INSTITUTE OF METALS

Essay Prize Competition

The Council of the Institute of Metals will present, annually, two prizes of 20 guineas each for the best essays submitted in accordance with the regulations of the competition. Each prize will be in the form of ten guineas in money and ten guineas in scientific, technical, or other appropriate types of books, to be selected by the prizewinner. If of sufficient merit, a prize-winning essay may be published in the Institute's "Bulletin" or selected for reading before a Local Section.

The Competition is open to all Student Members of the Institute, and to all Associate Members of Local Sections who are eligible for Student Membership of the Institute provided that both are within the normal age limits for Student Membership, *i.e.*, 17–25 years.

Candidates may select a subject which comes under one or other of the following two headings. One prize will be given under each subject.

(i) Non-Ferrous Foundry Practice
(ii) Metallography in Industry.

Further details may be obtained from the Secretary, The Institute of Metals, 4 Grosvenor Gardens, London, S.W.1.

Award of Medals

The Council of the Institute of Metals has made the following awards of medals for 1952 :

THE INSTITUTE OF METALS (PLATINUM) MEDAL to Mr. WILLIAM STANLEY ROBINSON, until recently President of the Consolidated Zinc Corporation, Ltd., in recognition of his outstanding services to the non-ferrous metal industries in developing the Australian zinc–lead industry and the British zinc industry.

THE ROSENHAIN MEDAL to Professor ANDRÉ GUINIER, Conservatoire National des Arts et Métiers, Paris, in recognition of his outstanding contributions in the field of physical metallurgy, particularly in connection with precipitation phenomena.

The W. H. A. ROBERTSON MEDAL to Mr. CYRIL ERNEST DAVIES, for his paper on "The Cold-Rolling of Non-Ferrous Metals in Sheet and Strip Form" (*J. Inst. Met.*, 1951, vol. 78, pp. 501–536).

NEWS OF SCIENCE AND INDUSTRY

Conference on Galvanizing

Following the success of the First International Conference on Galvanizing, held at Copenhagen in 1950, the Zinc Development Association is to hold a further conference at Düsseldorf from 30th June–4th July, 1952. The scope of this second Conference is being enlarged so that subjects discussed will include galvanizing of sheet, wire, and tube in addition to general galvanizing. Papers on fluxing, acid disposal, the cause of pot failures, the production of ductile coatings, and the galvanizing of wire will be among those presented.

Further details of the Conference may be obtained from A. R. L. Chivers, Esq., Zinc Development Association, Lincoln House, Turl Street, Oxford.

Italian Metallurgical Association

The Associazione Italiana di Metallurgia has notified its members that an increase of lire 1000 in all subscriptions is necessary to balance the rising costs of printing and similar services. From 1st January, 1952, the special reduced subscription rate to Members and Associate Members of The Iron and Steel Institute will, therefore, be lire 5000.

The Sixth National Congress of the Association will be held during the second fortnight of September, 1952, at a place yet to be decided.

Mechanical Engineering Board

Sir Andrew McCance, D.Sc., LL.D., M.I.Mech.E., F.R.S., has accepted the invitation of the Lord President to be Chairman of the Mechanical Engineering Research Board of the Department of Scientific and Industrial Research in succession to the retiring Chairman, Sir Henry Guy, C.B.E., D.Sc., M.I.Mech.E., F.R.S. Sir Andrew assumed office in February, 1952.

H. W. Gillett Memorial Lecture

The American Society for Testing Materials has established an annual H. W. Gillett Memorial Lecture. The Lecture, which is being sponsored in co-operation with the Battelle Memorial Institute, will commemorate Horace W. Gillett, who was one of America's leading technologists, the first Director of the Battelle Memorial Institute, and an active worker for many years in the ASTM.

Roll Makers' Association

The Secretaries of the Roll Makers' Association are Peat, Marwick, Mitchell and Co., Lombard House, Great Charles Street, Birmingham 3.

DIARY

1st April—INSTITUTION OF CHEMICAL ENGINEERS—Symposium on the Standardization of Stainless Steels—Geological Society, Burlington House, London, W.1, 5.30 P.M.

1st April—SHEFFIELD METALLURGICAL ASSOCIATION—"*Pure Oxide Refractories—Their Manufacture, Properties and Applications*," by D. Kirby—Grand Hotel, Sheffield, 7 P.M.

3rd April—STAFFORDSHIRE IRON AND STEEL INSTITUTE—Paper on Refractories—Station Hotel, Dudley, 7.30 P.M.

3rd April—LEEDS METALLURGICAL SOCIETY—"*Metal Spectroscopy*," by E. S. Dreblow—Chemistry Department, The University, Leeds, 7 P.M.

3rd April—INSTITUTE OF WELDING—"*Automatic Arc Welding*" film—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 7.30 P.M.

3rd–8th April—PHYSICAL SOCIETY—Exhibition—Imperial College, London, S.W.7.

4th April—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—"*Operating Experience with the Blast Furnace under High Top Pressure*," by R. P. Towndrow—39 Elmbank Crescent, Glasgow, 6.45 P.M.

7th April—CLEVELAND INSTITUTION OF ENGINEERS—"*Blast-Furnace Practice at Redcar Works*," by A. T. Ledgard—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough 6.30 P.M.

8th April—SHEFFIELD METALLURGICAL ASSOCIATION—"*Some Sources of Error in Chemical Analysis*," by T. B. Smith—Grand Hotel, Sheffield, 7 P.M.

12th April—SWANSEA AND DISTRICT METALLURGICAL SOCIETY—Annual General Meeting followed by Presentation of the Prizewinners' Papers—Central Library, Swansea, 6.30 P.M.

17th April—IRON AND STEEL ENGINEERS GROUP—18th Meeting—4 Grosvenor Gardens, London, S.W.1, 10.30 A.M.

17th April—STAFFORDSHIRE IRON AND STEEL INSTITUTE—Annual General Meeting—Station Hotel, Dudley, 7.30 P.M.

18th April—INSTITUTE OF METALS (Sheffield Local Section)—Joint Meeting with Sheffield Branch of the Electrodepositors' Technical Society—"*Corrosion of Iron and its Prevention by Deposits of Non-Ferrous Metals*," by U. R. Evans—The University, St. George's Square, Sheffield, 6.30 P.M.

18th April—LIVERPOOL METALLURGICAL SOCIETY—Annual General Meeting—Electricity Service Centre, Whitechapel, Liverpool, 7.0 P.M.

22nd April—SHEFFIELD METALLURGICAL ASSOCIATION—"*Metallurgy in the University of Sheffield*," by Prof. A. G. Quarrell—Grand Hotel, Sheffield, 7.0 P.M. (Revised date).

26th April–11th May—4TH LIÈGE INTERNATIONAL FAIR—Liège, Belgium.

30th April—INSTITUTION OF PRODUCTION ENGINEERS (Shrewsbury Sub-section)—"*Pressed Metals*," by J. M. Phillips—Walker Technical College, Oakengates, Salop, 7.30 P.M.

30th April–1st May—IRON AND STEEL INSTITUTE—Annual General Meeting—Royal Institution, Albemarle Street, London, W.1, 9.45 A.M., and later at 4 Grosvenor Gardens, London, S.W.1.

TRANSLATION SERVICE

(The previous announcement was made in the March, 1952, issue of the *Journal*, p. 290).

TRANSLATIONS AVAILABLE

No. 436 (Spanish). E. DIAZ-VARELA CEANO-VIVAS: "Magnetic Sheets." (*Instituto del Hierro y del Acero*, 1950, vol. 3, Apr./June, pp. 115–131).

No. 437 (German). H. WENDEBORN: "Recent Developments in Strand Sinter Plants." (*Stahl und Eisen*, 1951, vol. 71, Nov. 8, pp. 1212–1218).

No. 438 (German). E. FEIL: "Evaluation of Recorded Operational Data of Blast Furnaces Producing Foundry Iron." (*Stahl und Eisen*, 1950, vol. 70, June 22, pp. 541–543). (Translation prepared by Mr. E. Cohen and made available through the courtesy of the British Iron and Steel Research Association. Members of that Association may obtain copies free of charge on application to B.I.S.R.A.).

TRANSLATIONS IN COURSE OF PREPARATION

(Polish). K. RADZWICKI, W. MADEJ, and W. STRONZAK: "Briquetting of Ore Fines for Steel Plants." (*Prace Glównego Instytutu Metalurgii*, 1951, No. 3, pp. 173–181).

(Russian). K. A. OSIPOV: "On the Mechanism of Plasticity in Homogeneous Metal Alloys at High Temperatures." (*Izvestia Akademii Nauk SSSR, Otdelenic Tekhnicheskikh Nauk*, 1949, No. 9, pp. 1372–1377). (Translation made available through the courtesy of the National Physical Laboratory, Teddington, Middlesex).

(German). H. PANNEK: "Influence of Coil Weight and Roll Speed on the Hourly Output per Stand of Cold Rolling Mills." (*Stahl und Eisen*, 1952, vol. 72, Jan. 17, pp. 70–75).

(German). W. LUEG: "Rolling Output and Efficiency of Utilization of Cold-Rolling Stands in General Terms." (*Stahl und Eisen*, 1952, vol. 72, Jan. 17, pp. 75–79).

CHARGES FOR COPIES OF TRANSLATIONS—The charge for translations is £1 for the first copy and 10*s*. for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether they can be prepared for inclusion in the Series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

The New Quebec and Labrador Iron Ore Field. J. A. Retty. (*Proc. Roy. Canad. Inst.*, 1950–51, **16**, Series IIIA, 49–50). To date nearly all the deposits have been found as surface outcrops. The iron concentration is 55–65% and in 1950 the total estimated tonnage was 417,000,000.—B. G. B.

Air Lift to the Labrador Iron Fields. F. Illingworth. (*Mine Quarry Eng.*, 1951, **17**, Aug., 265–269). Heavy equipment is being moved night and day by aeroplane from Seven Islands on the St. Lawrence to Burnt Creek in the iron ore fields of Labrador.—R. A. R.

The Wabana Iron Ore Properties. C. M. Anson. (*Canad. Min. Metall. Bull.*, 1951, **44**, Sept., 597–602). The Wabana iron ore deposits lie under the floor of Conception Bay, Newfoundland, and operations are conducted solely from Bell Island. The principal iron-bearing minerals are hematite and chamosite, with local concentrations of siderite. It is estimated that $3\frac{1}{2}$–4 × 10^9 tons lie in beds of workable thickness, and within five miles of the island. Sales are made on the basis of a minimum of 50% Fe and a maximum of 12% SiO_2.—T. E. D.

Bechuanaland—The Development of Its Mineral Resources. A. G. Thomson. (*Min. J.*, 1951, **237**, Dec., 642–643). Surveys indicate the presence of large coal fields. Some promising bedded iron ores have been found and also high-grade hematite–magnetite replacement ores.—B. G. B.

Kyanite in Kenya, Angola, and Bechuanaland. W. E. Sinclair. (*Trans. Inst. Min. Met.*, 1951–52, **61**, Part 4, 171–172). A description is given of the Kenya plant and of the deposits recently found in Angola and Bechuanaland.

Mineralization at Castle-an-Dinas Wolfram Mine, Cornwall. D. Kear. (*Trans. Inst. Min. Met.*, 1951–52, **61**, Part 4, 129–140).

U.S. Steel's Iron Ore Discovery in Venezuela. J. D. Munson. (*U.S. Steel's Policies on Costs, Prices, Plants, Productivity*, 1950, Jan. 24, 33–39). The use of taconite ores to supplement the dwindling supplies of high-grade ore in the U.S.A. would result in higher costs, since beneficiation is necessary. A recently discovered deposit in Venezuela is to be developed by a subsidiary of the United States Steel Corp.—T. E. D.

Iron Ore is Available. B. F. Fairless. (*Business, Big and Small, Built America*; United States Steel Corp., 1950, Apr., 13–15). An adequate supply of iron ore in the U.S.A. is a problem of production and cost, not of exhausting the ore reserves of the country. United States Steel Corp. has about 19% of the estimated reserves; it sells ore to other companies, and will continue to do so.—T. E. D.

No Shortage of Iron Ore. J. G. Munson. (*Business, Big and Small, Built America*; United States Steel Corp., 1950, Apr., 17–24). The iron ore situation in America is reviewed, with special reference to the Lake Superior ores. The new source of high-grade ore in Venezuela is mentioned. The general policies of the United States Steel Corp. with regard to iron ore are outlined.—T. E. D.

Iron Ore: World Demand and Resources. T. P. Colclough. (*J. Inst. Met.*, 1952, **19**, Jan., 234–239: *Iron Steel*, 1951, **24**, Nov., 507–508). The author discusses the world's supplies of iron ore and considers whether the existing supplies are capable of meeting the requirements of the rapidly growing steel industry. The proposed iron and steel programmes can be met if the plans already formulated are fully implemented.—G. F.

The World's Iron Ore Supplies. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1951, **26**, Sept., 1–13). The article includes sections on workable ores, beneficiation, fines, blending, size and location of deposits, distribution, later sedimentary ores, magnetite ores, laterites, future supplies, American and British sources, American taconites, and supplies for Continental countries. Tables list the reserves of many ores, and a geological time scale is given.—E. C. S.

Titanium—A Critical Review with Special Reference to the Utilization of South African Resources. J. J. Frankel, A. M. Schady, and D. J. du Plessis. (*J. Chem. Met. Min. Soc. S. Africa*, 1951, **52**, Sept., 39–52). The authors survey the location and nature of overseas titanium deposits, methods of processing the ore, and new metallurgical developments. The possibilities of utilizing South African titanium resources are discussed. (66 references).—R. A. R.

ORES—MINING AND TREATMENT

New 56-Ton Iron-Ore Wagon. (*Iron Coal Trades Rev.*, 1951, **163**, Dec. 28, 1400). **New Waggons for Carrying Iron Ore.** (*Railway Gaz.*, 1951, **95**, Dec., 695). **Wagons for Iron Ore.** (*Engineer*, 1951, **192**, Dec. 21, 801). These new wagons each have four discharge doors which can be operated throughout an entire train simultaneously by compressed air. Corten steel has been used in the construction. The tare is about $28\frac{1}{2}$ tons and the load 50–56 tons.—B. G. B.

I.O. Co's. Giant Ore Loading and Storing System. (*Min. J.*, **237**, Dec., 640–641). This new plant has been constructed to handle the iron ore coming from the Labrador-Quebec ore fields. Its function is either to send the ore through to one of four stockpiles each having a capacity of 440,000 tons or to load it directly on to ships.—B. G. B.

Sintering of Iron Ores. Part I—The Theoretical Basis of the Sintering Process. W. Madej and B. Sewerynski. (*Prace Badawcze Glownego Inst. Met.*, 1951, **3**, No. 5, 351–359). [In Polish]. Properties influencing the suitability of ore fines for sintering and the preparation of sinter mixes, particularly in respect of fuel and water additions are discussed. The order and interdependence of chemical reactions and physical changes and the problems of porosity and strength of sinters are considered. As to the mineralogical composition of sinters, a description of minerals encountered is given and the problem of micro- and macroporosity is discussed. An attempt at a mathematical assessment of sinter plant efficiency is made.

Sintering of Iron Ores. Part II—The Effect of Suction on the Sintering Process. S. Holewinski, W. Madej, and B. Sewerynski. (*Prace Badawcze Glownego Inst. Met.*, 1951, **3**, No. 5, 361–374). [In Polish]. An investigation of the effect of the suction on the sintering time for different ore fines is described. Experiments were conducted with pans with a grate area of 0·04 sq. m. and later (to decrease the influence of walls) 0·34 sq. m. The apparatus is described. Sintering of four different ores was tested. Optimum coke additions to sinter mixes were based on the shortest sintering time and the smallest percentage of unsintered material together with the highest possible sinter quality. The following relationships are shown by graphs : (1) Amount of air drawn through the bed before and after ignition and the applied suction ; (2) sinter strength and suction ; (3) temperature of the charge and sintering time ; (4) temperature of combustion gases and sintering time ; and (5) applied suction and sintering time. Sintering of hematite fines with various additions of flue dust, roasted pyrites, ore concentrates (Fe 68·1%, SiO_2 3·04%) and iron turnings was tested, and the influence of these additions on the sintering process is discussed. For the majority of ores investigated there is an optimum suction of about 1200 mm. of water. Increasing the suction decreased the efficiency of the sintering process.—V. G.

New Developments in Agglomeration Processes for Iron Ores : A Review of Recent Work Dealing with Pelletising and Vacuum Extrusion Processes. (*Iron Coal Trades Rev.*, 1951, **163**, Dec. 7, 1247–1251). Recent work and new developments in agglomeration processes for iron ores are reviewed. The theory and requirements of pelletizing are considered, and a new internal combustion furnace for firing green pellets is described. The vacuum extrusion process of agglomeration is also discussed.—G. F.

New Rotary Unit Cools Sinter Economically. F. R. Greyson. (*Steel*, 1951, **129**, Nov. 19, 98–101). A description is given of a patented rotary sinter cooler at the Fontana plant of the Kaiser Steel Corp. The cooler is a bin rotating at about 2 rev./hr. The sinter takes about 2 hr. to cool and is continually extracted at the rate of 2500 cu. ft./hr.—A. M. F.

FUEL—PREPARATION, PROPERTIES, AND USES

The Production of High Temperatures in Industry by Town Gas. R. F. Hayman. (*Gas Times*, 1951, **69**, Nov. 30, 319–324 : *Inst. Gas Eng. Comm.* 396, 1951). Methods of producing high temperature (> 1350° C.) in a short time in a working chamber of appreciable size are dealt with. Problems of furnace design and the use of modern refractory materials are discussed. Studies of flow patterns have shown that attention to the design of combustion chambers could improve the performance and scope of existing plant. A saving of 19% in time and gas to raise a furnace to 1450° C. has been achieved with the new design.—B. G. B.

Fuel Economy IV—Furnace Efficiency. R. J. Sarjant. (*Research*, 1951, **4**, Dec., 562–568). A survey is made of the factors affecting furnace efficiency, and of methods of controlling these factors. Topics discussed are : Fuels and firing, furnace design and load, mechanization of charging and discharging furnaces, instrumentation of furnaces, and heat-recovery appliances.—C. J. B. F.

Coal Sampling by Large-Increment Weights. B. A. Landry and W. W. Anderson. (*Trans. Amer. Soc. Mech. Eng.*, 1951, **73**, Oct., 989–996). A sampling experiment is described that was aimed at determining the variance in percentage ash of large-weight, single-increment samples of an Indiana coal. The observed variance is broken down into its parts which are calculated from the data obtained.—D. H.

The Distribution of Coal Volatiles in the South Wales Coalfield and Its Probable Significance. O. T. Jones. (*Quart. J. Geol. Soc. London*, 1951, **107**, No. 425, 51–83).

Trends in European Coal Cleaning Practice. A. Grounds. (*Canad. Min. Metall. Bull.*, 1951, **44**, Sept., 603–609). The history of coal preparation in Europe is briefly considered. Special reference is made to Baum washers, dense-medium washers such as the Ridley-Scholes bath, and the Klöckner-Humboldt-Deutz process. The present trend is away from dry cleaning.—T. E. D.

Some Aspects of the Mechanism of Gasification of Carbon by Carbon Dioxide and Steam. J. D. F. Marsh. (*Inst. Gas Eng. Comm.* 393, 1951). Past work is surveyed and a review of proposed mechanisms to explain the retardation of the CO_2 reaction by CO and the steam reaction by hydrogen is made in the light of the present results.—B. G. B.

Some Considerations on Heat Balances in the Iron and Steel Industry. M. Martinez de la Escalera. (*Dyna*, 1951, **26**, Oct., 265–268). [In Spanish]. The author discusses the effects of some frequently forgotten factors on the heat balance in a battery of Otto coke ovens (60 ovens of 1000 tons capacity per day).—R. S.

Investigation Discloses Improvement in Beehive Coke. F. A. Dudderar. (*Steel*, 1951, **129**, Nov. 26, 98–106). Beehive coke from 25 plants in the Pittsburgh district has been studied. Considerable variations in sulphur, ash, and fuel value even on the same plant with the same coal were experienced but the following conclusions have been reached : A coking period of 48 hr. is preferable to 96 hr., higher fuel values were apparent in beehive coke compared with by-product coke but the percentage of plus 2-in. material was slightly less.

TEMPERATURE MEASUREMENT AND CONTROL

The Colour Temperature of Light Sources. H. G. W. Harding. (*Proc. Phys. Soc.*, 1950, **63B**, Sept. 1, 685–698). The definition of colour temperature is explained and the approximations of the spectral distributions of energy of lamps to those of black-body radiators are indicated. The value of colour-temperature measurements to the colorimetrist is outlined.

Steady Furnace Control. (*Elec. Times*, 1951, **120**, Dec., 1093). Control of electrical furnaces by resistance thermometers is rendered difficult by variations of the mains voltage and frequency. A new type of two-valve controller overcomes this problem. A description of the unit is given.—B. G. B.

Production Control of Molten Steel Temperature and Its Effect on Steel Casting Quality. C. A. Faist. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8**, 210–244). The author discusses the temperature control in electric furnace practice at the Burnside Steel Foundry Co., Chicago, and describes the methods of measuring bath and teeming temperatures, and ladle preheat.—G. F.

Platinum/Platinum-Rhodium Thermocouples and Their Industrial Applications. M. Chaussain. (*Inst. Brit. Found.*, June 12–15, 1951, Preprint No. 996 : *Found. Trade J.*, 1951, **91**, Aug. 9, 147–156 ; Aug. 16, 189–195). The development and use of the Pt/Pt–Rh thermocouple has finally led to a method of calibration by a standard reference curve, which enables them to be used for temperatures up to 1720° C. Thorium oxide affords the best protection against contamination of the thermocouple wires.—R. A. R.

Measurement of High Temperatures, the 1948 Temperature Scale. H. Willenberg. (*Technik*, 1951, **6**, Oct., 469–470). The changes are described in the legal definition of temperature measurement introduced in 1950 so as to conform with the new international temperature scale of 1948.—J. G. W.

Bibliography on the Measurement of Gas Temperature. P. D. Freeze. (*U.S. Nat. Bur. Standards, Circular No.* 513, 1951). This bibliography contains about 400 references covering the 20 years before January 1951. Temperatures which are of interest in hot gases moving at high velocities, as in gas turbines, are reviewed in a short introduction.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Appreciation of Blast-Furnace Stoves from the Standpoint of Flow and Heat Economy. M. Hansen. (*Stahl u. Eisen*, 1951, **71**, Aug. 30, 941–946). Types of checkerwork are considered from the viewpoint of pressure drop in flow and of heat transfer, and suitable design parameters are derived. Factors affecting the operation of hot-blast stoves, such as

hood space, combustion chamber, and burner design, are briefly discussed.—A. G.

Know the Properties of Ores for Pig-Iron Making. M. Kadlec. (*Hutnik* (Prague), 1951, **1**, No. 2, 31–32). [In Czech]. The evaluation of the quality of iron ores is explained, and the desirable features enumerated. Methods for the economic use of inferior ores in the blast-furnace are mentioned.—P. F.

Modern Development Tendencies in Pig Iron Production. O. Hájíček. (*Hutnik*, (Prague), 1951, **1**, No. 6, 122–123). [In Czech]. Methods of increasing the efficiency of extracting iron from lean ores are examined. A higher rate of heat input into the blast-furnace is the chief requirement. To increase the blast temperature would be uneconomical, but an increase in the available oxygen by increasing the blast pressure and by the addition of oxygen is possible. Experiments with different pressures of air and blast-furnace gas showed that simultaneous increases in gas pressure from 0·2 to 1·5 atm. and air blast pressure from 1 to 2·5 atm. facilitated an increase of 20% in the hourly rate of iron output and a coke saving of 15%. On the basis of large-scale experiments carried out in Russia, it can be said that a 30% reduction in the coke consumption is attainable.—P. F.

Some Possibilities of Increasing Output and Improving Blast-Furnace Performance. O. Hájíček. (*Hutnik*, (Prague), 1951, **1**, No. 7–8, 153–154). [In Czech]. Lining of blast-furnace hearths with carbon blocks, the use of oxygen-enriched blast, and the scope of increasing gas and air pressures in the blast-furnace are discussed. A blast-furnace at Dortmund had finished a successful 15-year campaign in 1942, having produced 3·7 million tons of pig iron with a carbon hearth. Twenty-eight break-outs had, however, occurred. Carbon linings in Europe are said to be inferior to those in the U.S.A. The thermal expansion of American firebrick lining is about half that of most European, which implies a more nearly linear expansion and comparatively tight-fitting joints. European specifications, by contrast, demand small additional shrinkage, which is not the same as low thermal expansion from the point of view of tight-fitting bricks. Of 77 blast-furnaces in the U.S.A. equipped with carbon hearths up to the middle of 1950, 17 are no longer in operation, but not because of poor performance. The use of increased blast pressures and of oxygen in pig-iron production is also critically examined.—P. F.

Method of Using Oxygen in the Blast-Furnace. O. Hájíček. (*Hutnik*, (Prague), 1951, **1**, No. 5, 104–106). [In Czech]. Early attempts to use oxygen in blast-furnace practice were uneconomic owing to inadequacy of equipment and high cost of oxygen. These limitations are being overcome, and a saving of 30% in the costs of blast-furnace operation is expected in spite of the cost of oxygen and the necessary CO_2 diluent. The advantages to be gained are explained.

Specific Throughput of Blast-Furnaces of Different Capacities. W. Wolf. (*Stahl u. Eisen*, 1951, **71**, Sept. 27, 1035–1037). Comparison of data from various iron-producing regions indicates that in general the specific throughput of a blast-furnace decreases with increasing hearth diameter. With readily reducible ores the greater spread of the softening zone slows down the rate of descent of the burden. With hard ores difficult to reduce, there is only a thin melting zone with a porous column of burden above it. Even large-diameter furnaces can operate under such conditions without overloading the blowing machinery.—J. P.

A Gas-Tight Device for Measuring the Blast-Furnace Stock Level. D. R. Brown and C. E. Wilson. (*J. Iron Steel Inst.*, 1952, **170**, Apr., 329–330). [This issue].

Observations on the Blast-Furnace with the Gas Probe. W. Wolf. (*Stahl u. Eisen*, 1951, **71**, Sept., 13, 986–991). Six months' records from a Bochumer-Verein recording gas probe, installed below the throat of a blast-furnace, indicate that continuous measurements of temperature and gas composition over the whole furnace cross-section make it possible to follow the gas distribution, to recognize troubles in good time, and to take precautionary measures. Optimum methods of operation and furnace profile for various burden conditions can thus be quickly determined without laborious investigations. Blast-furnaces designed to handle one type of ore work more efficiently than those which must deal with large variations in burdens. The gas probe, however, offers the possibility of discovering the best methods of operating even for changing burdens.—J. P.

Operational Results on a Blast-Furnace with a Reduced Charge Level and a Fine-Grain Burden. W. Wolf. (*Stahl u. Eisen*, 1951, **71**, Aug. 30, 922–925). A 29-m. high blast-furnace is reported to have operated satisfactorily with a 14·5-m. high stock column after the tuyere diameter had been reduced from 180 to 150 mm. and blast temperatures of 750–800° C. had been maintained. Pulverization prevented the charging of more than 650 to 675 kg./sq. m./hr. of coke. The iron produced from fine-grain ore could be easily converted into a Bessemer steel with low phosphorus and nitrogen contents.—A. G.

The Determination of Coke Consumption in Blast-Furnaces. F. Wesemann. (*Stahl u. Eisen*, 1951, **71**, Aug. 16, 873–877). Coke consumption in blast-furnaces is determined with an accuracy of ± 30 kg./ton pig iron by splitting the total into the amount required for heating and that required for reduction of the ore and carburization of iron. The total coke consumption depends primarily on the composition of the ore, the amount of slag, and also on indirect reduction, blast and gas temperatures, and other operational data. Examples of coke balance sheets are given.—A. G.

Determination of the Chemical Activity of Carbon in Liquid Iron. W. Wennmann and T. Kootz. (*Stahl u. Eisen*, 1951, **71**, Sept. 13, 992–994). Oxide films on exposed pig iron consist of iron silicates saturated with silica. They disappear above a certain temperature, due to reaction between silica and carbon dissolved in the iron. They reappear on cooling to this temperature, which may thus be regarded as the ignition temperature of the carbon. Increasing carbon content lowers the ignition temperature, and increasing the silicon in the iron raises it slightly. Melting time also influences the ignition temperature. With increasing time of overheating the carbon ignites more readily. A blast-furnace through which iron passes slowly appears to produce a metal with more easily removable carbon. This indicates that carbon can exist in an active form. The commercial significance is that a pig iron containing carbon difficult to ignite favours the formation of a slag, whereas an iron with easily reducible carbon could probably be blown without the formation of slag.—J. P.

Zapla Blast Furnaces. The Iron and Steel Plant of Palpalá (Argentina) and Its Recent Extensions. (*Ing. e Indust.*, 1951, **19**, Aug., 70–72). [In Spanish]. This non-technical note refers to the building of a second charcoal blast-furnace of improved design at Palpalá in Jujuy province of Argentina. All equipment was made in the Republic. National Zapla ore (red hematite 48% Fe) was used. Turbo-blowers provide air at 200 cu. m./min. The furnace has six tuyeres.—R. S.

TREATMENT AND USE OF SLAGS

Contribution to the Measurement of the Crushing Strength of Slags. F. Leclerc. (*Silicates Indust.*, 1951, **16**, Dec., 334–337). A semi-empirical formula is developed by means of which the crushing strength of concretes containing granulated basic slag can be determined in terms of the length of the temperature interval in which recalescence takes place on heating a sample in the furnace, and of the intensity of recalescence. The method provides results rapidly with good accuracy.—P. F.

Methods of Producing Blast-Furnace Slags in Lumps. A. Ofiok. (*Hutnik*, (Warsaw), 1951, **18**, June, 236–244). [In Polish]. The utilization of blast-furnace slags in lumps for road making and as fillers for bitumen surfaces, their manufacture, and properties are discussed.—V. G.

Sylvester Process Extracts Manganese from Slag. G. R. Sylvester. (*Steel*, 1951, **129**, Nov. 26, 84–85). A pilot plant using simple pyrochemical and mineral dressing operations is being used to recover 75 to 85% of the manganese and iron contained in open-hearth slag. Metallic content of the concentrate is about 50% and the only raw materials needed are slag, limestone or silica sand, small amounts of fluorspar, and waste coke.—A. M. F.

DIRECT PROCESSES

A New Process for Direct Reduction of Iron Pyrites. A. Scortecci. (*Metal Progress*, 1951, **60**, Oct., 72–75). The principle of the process discussed consists in the dissociation of pyrites in the absence of air, and in the presence of carbon, with the formation of iron and carbon disulphide. Iron yields in the tests described have been higher than 95%.

PRODUCTION OF STEEL

Steel Making in America. D. A. Fisher. (*United States Steel Corp.*, 1949). The history, manufacture, and uses of steel are described for the student and the layman. Two hundred photographs and drawings are included.—T. E. D.

Sault Ste. Marie, Ontario, Canada. (*Usco Mag.*, 1951, **2**, Oct., 13–15). A short description is given of this large Canadian steelworks.—B. G. B.

Planning Quality Control in the Production of Special Steels. H. Briefs. (*Stahl u. Eisen*, 1951, **71**, Aug. 16, 865–873). Measures for the production of high-quality steels with uniform predetermined properties are outlined and include careful planning of the whole manufacturing process, testing the products at all stages, statistical evaluation of operational data, and collaboration with steel users. Unjustified and excessive demands by the users may lead to the production of steels which deteriorate in further treatment or in use.

Integrating Flow Meter for Measurement of Converter Blast. R. Michaux and P. Leroy. (Soc. Française de Mét.: *Iron Coal Trades Rev.*, 1952, **164**, Jan. 11, 87–89). In an earlier paper these authors and F. Meyers and F. Renard described an integrating flow meter for measuring converter blast (*see J. Iron Steel Inst.*, 1950, 164, Apr., 486). The present paper describes an improved design which could serve as a prototype for production purposes.—R. A. R.

A New Type of Steelmaking Converter. (*Iron Coal Trades Rev.*, 1951, **163**, Dec. 21, 1355–1356). This article describes the Austrian experimental converter into which oxygen is blown at the top. *See* "Converter Steel Production with Oxygen Injection" (*J. Iron Steel Inst.*, 1952, **170**, Mar., 292).

Bessemer Steel Low in Nitrogen and Phosphorus. P. Coheur. (*Metal Progress*, 1951, **60**, Oct., 78–80). Studies at three Liége steelworks indicated that blowing with oxygen-enriched air or a mixture of steam and oxygen will produce basic-Bessemer steels exceptionally low in nitrogen and phosphorus, with ductility at least equal to that of normal open-hearth steel.—J. P. S.

Arches of High Rise Designed for Stability. J. D. Keller and J. S. McDowell. (*Blast Furn. Steel Plant*, 1951, **39**, Nov., 1358–1370, 1399). Catenary or compound-arch design permits the construction of furnaces in which there are no side walls as such, since a sprung arch with a high rise may take the place of both side walls and roof. The authors offer a simple method of designing and laying out such compound arches to obtain stability.—J. P. S.

Practical Consideration of Open Hearth Bottom Construction. P. A. Gaebe. (Amer. Inst. Min. Met. Eng.: *Blast Furn. Steel Plant*, 1951, **39**, Nov., 1338–1347). The author discusses comparative time, cost, and performance statistics between the fully rammed and conventional burned-in magnesite hearths of 225-ton furnaces. It should be possible to decrease the installation time by 35% for a rammed hearth as compared with grain magnesite construction.—J. P. S.

Aerodynamic Factors Associated with the Wear of Open-Hearth Furnace Roofs. J. A. Leys and E. T. Leigh. (*J. Iron Steel Inst.*, 1952, **170**, Apr., 336–342). [This issue].

How to Increase Steel Production. A. Děkanovský. (*Hutnik*, (Prague), 1951, **1**, No. 9, 186–188). [In Czech]. Czech steel is mostly of the basic open-hearth type. Factors leading to its more efficient production, including the human factor, furnace design, basic roofs, and use of oxygen are discussed.

How Melter Josef Bialožyt Works. (*Hutnik*, (Prague), 1951, **1**, No. 10, 210). [In Czech]. A description is given of a rationalized method of teamwork developed by chief melter J. Bialožyt in the open-hearth shop of the Třinec steelworks. Preparation of the charge, proportions and order of charging large and small scrap, lime, and liquid pig iron are described. A clean, intense, white flame is used at the beginning, the flame being as hot as is compatible with roof life. He strove to tap as much as possible of the foaming oxidizing slag. The composition of the remaining and newly formed slag accelerates phosphorus removal. The tapping and hot repair procedures are also given. The method has increased the throughput.—P. F.

How Melter Adolf Vytisk Works. (*Hutnik*, (Prague), 1951, **1**, No. 7–8, 158). [In Czech]. A melter at the Vitkovice steelworks describes his improved methods. A log for two consecutive heats is given. The time for charging 52 tons of heavy scrap was reduced from 2–2½ hr. to 35 min. but the faster rate cooled the furnace too much, and time thus gained was almost entirely lost on reheating. The optimum period for charging was finally determined at about 1–1½ hr. Charge distribution in the furnace, gas control, and additions of oxygen in the early melting stages are described.—P. F.

How I Melt Steel. M. Kučerin. (*Hutnik*, (Prague), 1951, **1**, No. 2, 34). [In Czech]. An open-hearth steel melter describes his methods of minimizing heat loss during pouring and charging, and the method of distributing the charge to facilitate handling.—P. F.

My Method for Rapid Steel Melting. A. Subbotin. (*Hutnik*, (Prague), 1951, **1**, No. 3, 52). [In Czech]. The author describes in detail methods of furnace hearth maintenance, roof temperature and fuel-flow control, and distribution of charge before charging and in the furnace. Furnace performance was 8·2 metric tons per sq. yard of furnace floor, and 279 heats between consecutive overhauls were attained. Each heat took 3½ hr., and four tons of oil per heat were saved by the improved technique.—P. F.

Duplex Processes for Improving Steel Quality. J. Mayer. (*Hutnik*, (Prague), 1951, **1**, No. 10, 211–212). [In Czech]. The potentialities of duplex steel production are discussed from the point of view of steel quality and economy.—P. F.

Thermal Balance of the Open-Hearth Furnace and Automatic Control. A. Benda. (*Hutnik*, (Prague), 1951, **1**, No. 11, 242–244; No. 12, 265–266). [In Czech]. The main features of the heat balance in the open-hearth furnace are considered. These are: Calorific value of fuel, temperature of gas and air after preheating, optimum size and emissivity of the flame in relation to furnace size, heat outflow from the furnace, checker temperature, gas-flow reversal, escape of smoke, and the optimum fuel/air ratio. The question of maintaining optimum flame temperatures by relating fuel input to charging speed is considered, and other methods of controlling the heat balance are discussed.—P. F.

Russian Experiences in Fast Steelmaking. V. Zacharov. (*Hutnik*, (Prague), 1951, **1**, No. 5, 107–109). [In Czech]. The author describes in detail the schedule adopted by his team for operating a Magnitogorsk open-hearth furnace. Charging, temperature control, use of instruments, tapping slag during the heat, and flame-emissivity control by kerosene additions to the fuel during slag formation are described.

Heating up Open-Hearth Furnaces after Cold Repairs. A. Děkanovský. (*Hutnik*, (Prague), 1951, **1**, No. 3, 55). [In Czech]. In established Czech practice open-hearth furnaces which had been repaired or rebuilt while cold, were brought up to melting temperature in 96–108 hr. Experiments carried out in the Třinec steelworks showed that a reduction to 54 hr. was possible without detriment to the furnace which has already produced over 300 heats.—P. F.

Low Sulphur Steel from High Sulphur Raw Materials and Fuel. F. L. Robertson, C. H. Bacon, and J. W. Till. (*Trans. Amer. Inst. Met. Eng.*, 1951, 1031–1044; *J. Met.*, 1951, **3**, Nov.). The authors discuss the development by John Summers and Sons, Ltd., of a process for making low-sulphur steel from high-sulphur materials. The principles adopted and processes used are described, and data collected on a furnace specially set aside to study the problem are given. Future developments are considered. The process could be modified to suit other works' conditions in cases where sulphur governs the slag bulk.—G. F.

The Factors Determining the Teeming Temperature of Open-Hearth Steel. D. Hadfield and A. Donald. (*West Scotland Iron Steel Inst. Preprint*, Dec. 14, 1951: *Iron Coal Trades Rev.*, 1952, **164**, Jan. 11, 79–81). The factors that may affect the temperature at which open-hearth steel is teemed are considered. From theoretical calculations of the probable effect of each, their relative importance is assessed. The theories put forward were tested by measuring the temperature in the ladle of a large number of charges, using a special pyrometer. The readings are analysed statistically to account for the wide variations found. These results make it possible to decide the temperature at which to tap steel of a given composition.

Fundamentals of Desulphurization in the Production of Basic Open-Hearth Steels. F. Harders, H. Grewe, and W. Oelsen. (*Stahl u. Eisen*, 1951, **71**, Sept. 13, 973–985). Desulphurization in basic open-hearth furnaces has been followed in 25 works heats and the findings confirmed by tests in

crucibles. The more sulphur introduced by the fuel gases during melting, the greater is the sulphur in the metal and slag after melt down. The heating gases can be sulphurizing or desulphurizing. The sulphur content of the steel at melt down tends to a limit fixed by the sulphur content of the gas phase. The sulphur in the steel at tap is partly dependent on the sulphur content at melt down. The decrease in sulphur in the bath during the boil decreases with increasing sulphur in the gases. Even with very high sulphur in the gas, the sulphur in the steel at tap was in the usual basic open-hearth range (0·025–0·035%). The good agreement between the relationships found from statistical examination of operational results and those from the small-scale tests indicates that desulphurization is controlled by the following equilibrium ratios: $K_1 = (S)(FeO)/[S]$; $K_3 = (S)/[S][C]$; and $K_4 = (S)(Mn)/[S][Mn]$, where all the K's are functions of the CaO/SiO_2 ratio. There was no evidence that desulphurization proceeded by the reaction [FeS] + [Mn] = (MnS) + [Fe].—J. P.

Economic Efficiency in Steel-Melting Shops: Practical Trials to Increase Efficiency of Operating Plant. A. Jackson. (*Iron Coal Trades Rev.*, 1951, **163**, Nov. 23, 1119–1128). The author describes some of the practical trials in recent years at the Appleby-Frodingham Steel Co. First, the modifications made to two types of ingot mould are described and the resulting improvement in mould performance is illustrated. Next a summary is given of furnace roof trials which have resulted in the use of super-duty bricks where roof attack is greatest and in the insulation of ordinary roof blocks where the least wear takes place. The practice of oxygen-lancing the bath is then considered, and finally the training of melting-shop personnel and the administrative arrangements are discussed.—G. F.

Manufacture of Heat-Resisting Chromium–Molybdenum Steel. W. Becker. (*Giesserei*, 1951, **38**, Nov. 1, 581–583). Making a Cr–Mo heat-resisting steel for use in steam plant castings is described in detail, a typical heat record being quoted as an illustration of melting procedure.—J. G. W.

The Use of Oxygen in Steelmaking. D. J. O. Brandt. (*J. B'ham Met. Soc.*, 1951, **31**, June, 44–60). A description is given of the use of oxygen, which is blown into the metal bath, in the manufacture of stainless and low-carbon silicon steels, and in both open-hearth and Bessemer practice.

Towards More Economical Electric Steel Production. V. Keclik. (*Hutnik*, (Prague), 1951, **1**, No. 11, 241–242). [In Czech]. Manganese, chromium, vanadium, and tungsten are generally lost by oxidation if present as scrap in the electric furnace. They can be saved if, instead of the oxidation process, the reducing-slag method is employed. Strict scrap control is necessary, carbon and phosphorus especially have to be kept within close limits. Sulphur is removed by the reducing slag. As oxidation, slag removal, and lime additions are not involved about 20% time saving is achieved. Research by F. P. Edernal on the gas content of electric steels made by this method is mentioned. The addition of dry limestone into the melt was recommended by him. The CO liberated during the heat carries part of the nitrogen and hydrogen from the melt. The quality of the steel is similar to that made by the normal oxidizing method. The problem of steelmaking by the reducing-slag method in the electric furnaces is looked upon as solved.—P. F.

Performance Data of Electric Furnaces Using Blown Metal. F. Badenheuer and H. Schweiger. (*Stahl u. Eisen*, 1951, **71**, Sept. 27, 1029–1035). Investigations on 12 electric arc furnaces using blown basic-Bessemer metal have permitted a relationship to be drawn up between bath diameter and charge weight for most efficient output and the optimum times of refining and finishing to be established. This made it possible for the works participating in the investigation to compare operational methods and in some instances to increase output considerably either by increasing charge weights or by adopting new methods.—J. P.

Continuous Steel Casting Pilot Plant Proves Successful. D. I. Brown. (*Iron Age*, 1951, **168**, Sept. 20, 113–118). The Allegheny Ludlum Steel Corp. are installing a new unit working on the Rossi principle for casting slabs and ingots with a cross-section up to 150 sq. in. at a speed of 15 ft./min. A pilot plant has been successfully casting carbon, stainless, and other alloy steels, and operations with this machine are described. The distinguishing feature is the oscillatory motion of the copper mould which has a maximum travel of 2 in. Greater cooling rates are possible as the mould is in contact with the cast bar for a longer period and the upward motion helps to break the mould away from the thin solidified skin.

FOUNDRY PRACTICE

Modern Foundry Methods—Industry-Sponsored Research. R. R. Lubker. (*Amer. Foundryman*, 1951, **20**, Nov., 51–53). The foundry research equipment and some work done with it at the Armour Research Foundation of the Illinois Institute of Technology are described. The furnaces include induction heating units from 20 to 600 lb. in capacity, a 300-lb./hr. cupola, a 250-lb. rocking indirect-arc furnace, and a 3000-lb./hr. cupola.—R. A. R.

Developing a Pilot Foundry. C. B. Stone. (*Foundry*, 1951, **79**, Nov., 98–100). A pilot foundry can prove very useful for establishing the best full-scale practice for short-run jobs and difficult castings, as well as providing experience for trainees.—E. J. D. S.

Casting Soundness Can Be Controlled. C. R. Austin. (*Steel*, 1951, **129**, Nov. 12, 81–82). The necessity for consultation between foundry technologist and designer in the problem of obtaining casting soundness is stressed. Examples are given of the effectiveness of Meehanite where uniform solidity is required.—A. M. F.

How to Use the Cupola. B. P. Mulcahy. (*Foundry*, 1951, **79**, Jan., 138, 141, 144; Feb., 186, 188–189; Mar., 202, 204; Apr., 171, 174; Sept., 154, 156; Dec., 250, 252; 1952, **80**, Jan., 152–155). This is a comprehensive account of cupola operation with special reference to the fuel aspect.—R. A. R.

Rigid Controls and Standards Improve Duplexing Operations. F. Coghlin, jun. (*Amer. Foundryman*, 1951, **20**, Sept., 24–27). Duplex melting with the cupola and an air or electric furnace is discussed from the point of view of improving the general efficiency of the cupolas, *e.g.*, by dust control and recuperation of waste heat, control of furnace lines, selection of the best refractories, and the setting up and subsequent revision of standards for operating techniques.—E. J. D. S.

The Effect of the Burn-Out of a Cupola Melting Cast Iron with Special Reference to Water-Cooled Cupolas. G. L. Jones and F. van Bergen. (*Metalen*, 1951, **6**, Nov. 15, 397–404). [In Dutch]. Factors affecting the burn-out and the damage resulting therefrom are stated. The cupola used was lined with 50% fireclay and 50% silica. The height of the coke bed was maintained at 1250 mm. above tuyere level. Charge weight was 500 kg. The depth of burn-out above each tuyere was measured after each of three casts. Burn-out can be reduced by water-cooling the melting zone.—R. S.

Air Preheater Unit for Small Cupolas Aids Melt Efficiency. L. G. Berryman. (*Amer. Foundryman*, 1951, **20**, Nov., 40–42). A simple heat exchanger to provide hot blast from cupola waste heat is described. Calculations are introduced to indicate the normal extent of heat loss in cupola operation.—E. J. D. S.

Contribution to the Laws of Cupola Melting. W. v. Preen. (*Giesserei*, 1951, **38**, Nov. 15, 598–600). The cupola process is described in terms of heat-balance equations. The usefulness of these equations depends on whether the ratios of the heat contents, flue gases, and slag can be determined with sufficient accuracy.—J. G. W.

Improving Cupola Operation with Oxygen-Enriched Blast. R. O. Day. (*Foundry*, 1951, **79**, Sept., 84–87). The use of oxygen-enriched blast has been found to reduce recovery time after a shutdown, restore favourable melting temperatures, and permit higher iron/coke ratios and efficient cupola operation on low-quality coke.—E. J. D. S.

Foundries Join in Developing Cupola Emission Control Unit. T. L. Harsell, jun. (*Amer. Foundryman*, 1951, **20**, Aug., 42–44). A wet gas washer to clean the gases emitted by a cupola and the operation and efficiency of the final design are described.—E. J. D. S.

Gray Iron Heat Conservation. Prevent Temperature Loss from Furnace to Mold. R. A. Clark. (*Amer. Foundryman*, 1951, **20**, Oct., 40–43). Improvements in handling methods and minor changes in existing equipment can result in substantial reductions in the 300 to 400° F. temperature loss experienced between furnace and mould. Tapping losses can be reduced by enlarging the cupola tap-hole and pouring more quickly through a covered and shorter spout, and providing covers for ladles.—E. J. D. S.

The Development of Nodular Cast Iron in U.S.S.R. J. Piaskowski. (*Przeglad Odlewnictwa*, 1951, **1**, Oct., 277–281). [In Polish]. A survey of Soviet literature concerning nodular cast iron is given. The types of spheroidal iron produced

in U.S.S.R. and scientific theories concerning graphite spheroidization are briefly mentioned. The results of laboratory investigations on the influence of the individual components on crystallization of spheroidal graphite are given.

Formation of Nodular Graphite in Cast Iron. A. Wittmoser. (*Giesserei*, 1951, **38**, Nov. 1, 572–577). The author shows by reference to microscopical investigations that the primary structure of cast iron is fundamentally changed by the magnesium treatment, in that the graphite is found predominantly in globular solid solution crystals. He concludes that the magnesium treatment and similar nodulizing treatments act through the destruction of nuclei favouring the normal crystallization of graphite, consequently the solid solution is supersaturated with carbon, which eventually forms graphite nodules.—J. G. W.

Some Experiments in Preparing Nodular Iron. W. P. Fishel and R. C. Bramlette. (*Amer. Foundryman*, 1951, **20**, Sept., 55–56). Various additions were made to 800-g. foundry iron melts. Completely nodular iron was produced with 6 to 10 g. of pure magnesium, Dow metal C, and aluminium–magnesium alloys. Some nodular iron was obtained by using calcium, calcium–iron alloy, and lithium, but its occurrence was limited to the outer portions of melts cast in thin-walled steel moulds. An 80/20 Mg–Al alloy was found to be very satisfactory. Completely nodular iron was also produced from high-phosphorus irons. Quenching and annealing experiments suggested that completely graphitized nodular iron could be produced by quenching castings poured into the steel moulds, and subsequently annealing them for a short time.—E. J. D. S.

Graphite Nodules—A Note on Spherulization of Graphite in Cast Iron. F. H. Buttner, H. F. Taylor, and J. Wulff. (*Amer. Foundryman*, 1951, **20**, Oct., 49–50). The authors present a possible explanation of nodule formation based on (1) Bernauer's spherulitic growth mechanism, (2) the authors' work on interfacial energies of metals, and (3) the Becker nucleation theory. From surface energy and thermodynamic considerations the explanation seems to lie in an evaluation of the interfacial energy between the liquid and the growing graphite particle, particularly in understanding the behaviour of graphite surfaces as affected by foreign atoms. For example, high-sulphur, commercial grey iron, when melted under helium, wetted the pure graphite crucible used. Remelted nodular iron did not.—E. J. D. S.

Melting Control Pays Off in Malleable Foundry. E. Bremer. (*Foundry*, 1951, **79**, Oct., 98–101, 264–266). The observed metallurgical and economic advantages of the cupola/electric-furnace process over all-electric duplexing for the large-scale production of malleable iron are described. Hot-blast cupolas were used with coke/iron ratios of 1 : 10, 1 : 12, and 1 : 13. Humidity of the blast was controlled with lithium chloride solution.—E. J. D. S.

Malleable Iron Then and Now. J. H. Lansing. (*Foundry*, 1951, **79**, Oct., 92–97, 267–268). In 1826 S. Boyden, while trying to make white-heart malleable iron which had been invented a century earlier by Reaumur, accidentally produced a superior quality of malleable iron now known as American malleable iron or black-heart iron. The cause of this success was the higher silicon and lower sulphur contents of the raw materials. The story of Boyden's discoveries and the growth of the American malleable iron industry are outlined.

Production of Cast Rolling-Mill Housings. (*Hutnik*, (Prague), 1951, **1**, No. 7–8, 164–166). [In Czech]. The production of cast steel rolling-mill stands measuring approximately 27 × 12 × 5 ft. is described. One diagram, two engineering drawings, and 12 photographs, taken at various stages of the work, are shown. The final casting was entirely within specified tolerances; its length being 0·1 in. greater than that specified.—P. F.

Developments in the Parlanti Casting Process. (*Machinery*, 1951, **78**, Jan. 4, 3–8). The Parlanti casting process employs 2L33 aluminium alloy dies, the surfaces of which are anodized to form a refractory barrier preventing fusion between molten metal and the die. Heat-resisting steels have been satisfactorily cast. When casting steel, an advantage is that alloying elements such as chromium and nickel which are put in to provide the desired dispersal and formation of carbon, may be eliminated as it is claimed that the rapid heat transfer in the Parlanti process provides for this.—R. A. F.

Things We Know and Don't Know about Cast Steel. C. E. Sims. (Amer. Foundrymen's Soc.: *Foundry*, 1951, **79**, Sept., pp. 92–97, 241–253). The author presents a critical discussion of what is generally accepted concerning the boil, gases in steel, the functions of slags and slag control, and the choice and use of deoxidizers in steelmaking.—E. J. D. S.

Casting of Steel Trolley Wheels in Metal Moulds. D. I. Sysojev and A. A. Barannikov. (*Hutnik*, (Prague), 1951, **1**, No. 9, 195–198). [In Czech]. A detailed description is given of the development of a continuous, mechanized, mass-production method of making cast steel trolley wheels, carried out in the Voroshilov Machine Building Plant in the U.S.S.R. In the new process complete wheels are cast in batteries of metal moulds, the design of which, and difficulties which had to be surmounted in the process of developing them, are described.—P. F.

Foundry Sand Control—No. 1 Enemy of Scrap. G. W. Anselman. (*Amer. Foundryman*, 1951, **20**, Oct., 52–57). Eleven defects in iron castings are said to be directly attributable to the type and quality of sand. Sand may also contribute to other defects such as scars, plates, hard spots, warping, misruns, and inclusions. How such defects in castings can be avoided by the correct sand preparation and moulding technique is described.—E. J. D. S.

Impact Strength of Sands. H. W. Dietert. (*Foundry*, 1951, **79**, Aug., 150–151). Five foundry sands were selected for tests to determine the importance of impact testing of sands. Compressive, tensile, and shear strength properties were measured and their values shown graphically in relation to impact strength, density, toughness, and green deformation. Green compressive strength and green deformation values give more detailed information concerning the working strength than any single strength test.—E. J. D. S.

Controls for Green Working Strengths of Molding Sands. H. W. Dietert. (*Amer. Foundryman*, 1951, **20**, Sept., 32–34). Methods for the complete control of green strength and green deformation of moulding sands, by which either may be varied independently at selected levels, are described. An indicating type of deformation tester was employed. When green deformation of high-strength sands for iron foundries is held in the range 0·016 to 0·020 in./in., a good mouldable sand is obtained which withstands severe conditions.

Rapidly Drying Russian Core and Mould Mixtures. I. B. Kumanin and A. M. Ljass. (*Hutnik*, (Prague), 1951, **1**, No. 6, 132–134). [In Czech]. The composition, preparation, and drying characteristics of core mixtures used in Russia for all classes of core, are given.—P. F.

Quality Classification of Patterns. J. Krčmář. (*Hutnik*, (Prague), 1951, **1**, No. 2, 40–43). [In Czech]. The design and preparation of wooden patterns for castings are surveyed, and the types of wood and finishing process appropriate from the point of view of frequency of use of a pattern and the tolerances demanded in the castings are discussed.—P. F.

The Pattern Engineer and the Foundry. G. A. Pealer. (*Foundry*, 1951, **79**, Oct., 102–103, 258–259). Examples of the choice available in pattern equipment are cited and recommendations on selection are made.—E. J. D. S.

Wood for Patterns. E. M. Davis. (*Amer. Foundryman*, 1951, **20**, Oct., 45–46). Types of wood suitable for pattern purposes, properties, and methods of processing are described. The moisture contents of these woods, and shrinkage on drying, are important factors.—E. J. D. S.

KO Risers are OK. L. C. Hollien. (*Amer. Foundryman*, 1951, **20**, Oct., 30–32). The application of knock-off or necked-down risers to castings for the oil industry weighing between 2000 and 4000 lb. is described. Although risers for this size of casting range from 20 to 28 in. in dia., the riser technique can be applied to smaller varieties. By knocking off the riser from the casting at the shake-out, considerable savings are effected. The area requiring grinding down to casting contour is reduced by 93%.—E. J. D. S.

Calculating Riser Dimensions—A Basic Approach to Risering Gears. R. A. Willey. (*Amer. Foundryman*, 1951, **20**, Nov., 46–50). Riser dimensions can be worked out on the basis that the freezing rate of a casting or section of casting can be estimated by a comparison of the surface areas dissipating heat and the respective volume, or the ratio of section surface area to section volume. Freezing rates for risers of various sizes are tabulated.—E. J. D. S.

Soil Mechanics Aids Study of Mold Behavior under Vibration. D. M. Marsh. (*Amer. Foundryman*, 1951, **20**, Oct., 36–39). When a matchplate is vibrated it is believed to be influenced

by such factors as passive earth pressure, ratio of induced frequency to natural frequency of the moulding-sand mass, and the directional nature of the vibrations. These observations and accompanying experiments form an introduction to further investigations.—E. J. D. S.

Casting Surfaces Produced in Olivine Molding Sand. G. S. Schaller and A. M. Nelson. (Foundry, 1951, **79**, Oct., 110–113, 260–263). The authors describe tests used to study the quality of casting surfaces produced in olivine moulding sand.

Use of Mercury in Mould Making. (*Hutnik*, (Prague), 1951, **1**, No. 2, 45–47). [In Czech]. The new Mercast method of using mercury to prepare thin-walled ceramic moulds for grey iron or steel castings, is described. Mass production of complicated castings within ± 0·020 in. is facilitated. An exact metal mould is filled with mercury and submerged into an acetone bath at − 57° C., when a true negative of solid mercury is obtained. This is then repeatedly submerged in anhydrous ceramic pastes and dried until a solid ceramic coating 0·33 in. thick is obtained. The frozen mercury is then melted by spraying the mould with mercury at 18° C. The mercury is cleaned and can be used again. The mould is heated at 1010° C. for 3 hr. and is then ready for repeated use.—P. F.

Joint Production Committee Solves Problem of Permanent Moulds. J. Šedina. (*Hutnik*, (Prague), 1951, **1**, No. 3, 50). [In Czech]. Several examples are given of savings achieved by improvements in casting technique relating mainly to the repeated use of moulds for large similar castings. The cement–sand process applied to 3-ton segment-shaped castings is described.—P. F.

500-Pound Casting Made in Permanent Mold. (*Foundry*, 1951, **79**, Sept., 152). A 10-ton iron mould is described, which was designed for making 500-lb. aluminium castings. These products are reported to have superior physical properties and a better finish than those cast in sand. Other advantages are man-power almost halved, and output increased.

Investment Casting. G. A. Tomkinson. (*Metal Ind.*, 1951, **79**, Oct. 12, 315–318; Oct. 19, 335–338). A general description is given of the several stages involved in investment casting of small parts.—P. M. C.

Centrifugal Casting of Pipe in Sand-Lined Molds. K. R. Daniel. (*Mech. Eng.*, 1951, **73**, Aug., 644–648). The author gives a short history of pipe making and discusses vertical pit-cast pipes and the horizontal centrifugal casting of pipes in sand-lined moulds.—D. H.

Heat Transfer Coefficients of Centrifugal Casting. C. L. Register, H. F. Taylor, and B. G. Rightmire. (*Amer. Foundryman*, 1951, **20**, Nov., 34–37). A technique is described whereby temperatures were observed by thermocouples in spinning cylindrical moulds and tubular castings. The heat-transfer coefficients of the mould-casting interface and the mould–air interface were computed. The coefficient for the condition mould to air was of the order 14 B.Th.U./hr./sq. ft./°F.

Studebaker Doubles Foundry Capacity. R. H. Moore. (Foundry, 1951, **79**, Aug. 72–79; Sept. 98–105; Oct., 114–119; Nov., 102–107, 214, 216). The modernization, layout, and equipment in this foundry are described. The last part of the series is devoted to the handling of castings at the shake-out and subsequent cleaning processes.—E. J. D. S.

Research is Important. E. Bremer and J. B. McFarland. (*Foundry*, 1951, **79**, Nov., 88–91, 198). The growth of the research and development department of the United States Pipe and Foundry Co., and its present layout and capacity are described and illustrated.—E. J. D. S.

Mechanical Aids. (*Found. Trade J.*, 1951, **91**, July 19, 65–68, 70). Sand-preparation plant, the sandslinger, and mould-handling equipment at the foundry of S. Russell and Sons Ltd., Walsall, are described.—R. A. R.

The Application of Mechanisation to Foundries. H. H. Shepherd. (*Australian Foundry Trade J.*, 1951, **2**, July, 5, 7). This is a very brief review of the economic importance of mechanization.—P. M. C.

Grey-Iron Foundries in Italy. G. Coppa-Zuccari. (*Australian Foundry Trade J.*, 1951, **2**, Aug., 9, 10). Statistics relating to sizes, numbers, outputs, and manpower of Italian foundries are given. Their total capacity is about 550,000 metric tons per year.—P. M. C.

Steel Castings: Layout for Varied Production at Grimesthorpe Foundry. (*Iron Steel*, 1951, **24**, Nov., 493–496). The layout of the Grimesthorpe steel foundry of the English Steel Corporation, Ltd., is completely different from that of most other British steel foundries, chiefly owing to the variations in size and quantity of castings produced. The different departments of the foundry and the production methods are described.—G. F.

From the Experience of Russian Standardization. F. Julis. (*Hutnik*, (Prague), 1951, **1**, 219–220). [In Czech]. Russian standard nomenclature and classification of faults occurring in steel castings are tabulated as in the specification GOST 4009-48.—P. F.

The Determination of the Viscosity of Molten Metals. M. R. Hopkins and T. C. Toye. (*Proc. Phys. Soc.*, 1950, **63B**, Oct. 1, 773–782). A method is described for the measurement of the viscosity of molten metals at temperatures up to 900° C. The metal is contained in a cylindrical crucible which is allowed to oscillate about its axis under the control of the torsion in a suspension wire.—C. J. B. F.

Study of Metal Flow in Sand Molds. G. D. Sylvestro. (*Foundry*, 1951, **79**, Oct., 104–109, 200–201). Studies to determine how metal should flow into a mould facilitates designing gating systems. In the experiments reported, the author used transparent materials for constructing the mould.

A System for Cooling Castings. (*Mech. Handling*, 1951, **38**, Dec., 472–476). The article describes an installation for cooling castings in the mechanized foundry of W. A. Baker and Co., Ltd., Newport, Mon. It explains how a casting-cooling conveyor and slat conveyor have aided the production programme.—D. H.

Economical Repair of Casting Defects. V. Oliverius. (*Hutnik*, (Prague), 1951, **1**, No. 10, 215–218). [In Czech]. Methods of repairing defects in steel and grey-iron castings are discussed, and a method for making grey-iron welding rods in the foundry, using aluminium and ferrosilicon additions, is described.—P. F.

Impregnation Cuts Casting Rejects. M. J. Nathason. (*Iron Age*, 1951, **168**, Sept. 6, 115–117). A thermosetting copolymer capable of withstanding extreme pressures and temperatures, which does not react with industrial gases and liquids, is a new solution to the problem of sealing porous castings. A batch process can be employed using an autoclave and a curing oven. The process can also be used for bonding sleeves and inserts of similar and dissimilar materials.—A. M. F.

Effect of Boron on Cast Iron. W. G. Wilson. (*Foundry*, 1951, **79**, Sept., 88–89, 164–165). Boron refines the structure, deepens the chill, and increases the hardness of irons used for rolls. This element added as ferroboron or in combination with a copper–chromium alloy is recommended as a substitute for more conventional additions to iron castings. The boron addition is about 0·05%, but where depth of chill is particularly required this amount may be exceeded.—E. J. D. S.

New Chromium Alloy Neutralizes Effect of Varying Cooling Rate in Gray Iron. R. A. Clark. (*Foundry*, 1951, **79**, Aug., 94–97). Tests on cylinder blocks cast from irons treated with a new chromium–silicon alloy (nominally 30% Si, 50% Cr) showed that the stabilizing tendency of the chromium combined with the inoculating influence of the silicon produces a marked improvement in the iron. The alloy composition gives the benefits of the chromium addition without increasing the tendency to chill.—E. J. D. S.

Reduction of Dust in Steelfoundry Operations. W. A. Bloor. (*Inst. Brit. Found.*, June 12–15, 1951, *Preprint No.* 1008: *Found. Trade J.*, 1951, **91**, July 12, 31–40, 46). Research on dust in foundries by the Brit. Iron Steel Res. Assoc. is reported. Methods for measuring and continuously recording dust concentrations are described. Dust concentrations vary greatly in different foundries and from operation to operation. More fundamental work on the effect of foundry dust upon animal systems is also described.—R. A. R.

HEATING FURNACES AND SOAKING PITS

Induction Heating in the Drop-Forging Industry. G. W. Seulen. (*Metal Treatment and Drop Forg.*, 1951, **18**, Nov., 483–489). Various induction heating units for use in forges and their advantages and disadvantages are described. The author indicates that medium-frequency plants are used exclusively by the forging industry and discusses their electrical arrangements.—P. M. C.

Salt Baths for Metal Treating. P. O'Keefe. (*Mat. Methods*, 1951, **34**, Oct., 115–130). Molten salt baths can be used for almost all heating and heat-treating processes. The article gives design and operating information on all the following processes: Carburizing and cyaniding; neutral hardening;

high-speed steel treatment; isothermal heat-treatments; annealing; tempering and colouring; brazing; cleaning and descaling; and heating for forging and forming. Forty-seven typical bath compositions are given.—P. M. C.

The Use of the Salt Bath in Forging. H. E. Boyer. (*Steel Processing*, 1951, **37**, Aug., 393–397; Sept., 463–466). The author emphasizes the many advantages of salt-bath billet heating over conventional radiation-type furnaces. Immersed and submerged electrode types of bath are described and illustrated. The high operating speeds, lack of scale, lower die wear, lack of decarburized layer, and uniformity of heating are all discussed, with particular reference to the hot extrusion of steel and to cyclic annealing after forging.—P. M. C.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Heat-Treatment of Grey Iron. M. Dubowicki. (*Przeglad Odlewnictwa*, 1951, **1**, Oct., 300–306). [In Polish]. The improvement of the mechanical properties of grey iron is discussed.—V. G.

The Significance of the Iron–Carbon Diagram in Heat Treatment. R. Whitfield. (*Machinery*, 1951, **79**, Sept. 13, 452–455). A diagram shows various alloy phases of iron and carbon and covers steels with up to 1·7% C and temperatures from 200 to 1650° C. The diagram is discussed in connection with pearlite and the constitution of steel, hardening, tempering, annealing, normalizing, spheroidizing, case-hardening, nitriding, forging, rolling, and mechanical working.—E. C. S.

Austempering. J. Lomal. (*Machinery*, 1951, **79**, Sept. 20, 503–505). The process involves raising the temperature of a steel until its structure is fully austenitic and quenching in a bath of molten lead or salts maintained at a temperature below that of pearlite formation and above that of martensite formation (usually between 260 and 370° C.). The limitations of sectional thickness, advantages of hot quenching, treatment of grey-iron castings, and a modified austempering process are dealt with.—E. C. S.

Corrigendum

In the *Journal*, 1951, Nov., p. 293, col. 2, penultimate line, for 'D. M. Dorey' read 'D. M. Dovey.'

Comparative Surface-Hardening Characteristics of Commercial Pearlitic Malleable Irons. S. H. Bush, W. P. Wood, and F. B. Rote. (*Trans. Amer. Soc. Mech. Eng.*, 1951, **73**, Nov., 1093–1099). Nine pearlitic malleable irons, produced in different ways and of widely differing composition and microstructure have been investigated to determine the hardness and effective case depth with different hardening treatments. Flame and induction heating, followed by oil, water, or spray quenching were used. Case hardness and depth were determined by Rockwell tests and metallographic examination. One structure, a dense pattern of extremely small spheroids of cementite, was most responsive to all types of treatment. In surface hardening at all frequencies there was an optimum power input which minimized the influence of microstructure to a pronounced degree.—D. H.

Stamps, Dies, and Punches: Treatment and Metallurgical Control at Edward Pryor & Son Ltd. (*Iron Steel*, 1951, **24**, Nov., 523–526). This article describes the heat-treatment equipment, practice, and metallurgical control used at the Sheffield works of Edward Pryor and Son, Ltd., in the manufacture of stamps, dies, and punches.—G. F.

Application of the Isothermal Transformation Diagram to the Normalizing of En 40C Steel. J. A. Cameron. (*J. Iron Steel Inst.*, 1952, **170**, Apr., 313–320). [This issue].

Electrode Salt Baths. (*Wire Industry*, 1951, **18**, Sept., 785–789). Equipment manufactured by Wild-Barfield Electric Furnaces, Ltd., Watford, is described.—J. G. W.

Use of Sawdust for Case-Hardening. V. P. Gerasimov. (*Stanki i Instrument*, 1950, No. 3, 26). [In Russian]. The use of sawdust from coniferous wood instead of charcoal is said to have reduced the time required for case-hardening to a given depth by 3 hr. The sawdust is heated to 500° C. in closed containers before use.—S. K.

Vertical Shaft Surface Hardening. (*Machinist*, 1951, **95**, Oct. 20, 1600–1601). The vertical shaft-hardening machine produced by Birlec, Ltd., Erdington, Birmingham, is used by automobile engine manufacturers for surface hardening certain types of steel shaft. A feature is its ability to harden only selected portions of the shaft, *e.g.*, the journal.—E. C. S.

Strength and Wear of Induction and Case-Hardened Spur Wheels. H. Glaubitz. (*Stahl u. Eisen*, 1951, **71**, Sept. 27, 1040–1044). Running tests have been conducted on small induction- and case-hardened gear wheels of alloyed and unalloyed steels to determine the resistance to wear, hardness, transverse strength, and bending fatigue limits. Induction hardened gears exhibited a more uniform depth of hardened rim. Adequate surface hardnesses up to 60 Rockwell C were obtained with both induction- and case-hardened wheels. Distortion was no greater with induction hardening. The results of the transverse strength and bending fatigue tests were in good agreement. The induction-hardened gears were superior in impact strength; the wear resistance of the two types of gear was the same.—J. P.

Steels for Flame, Induction and Immersion Surface-Hardening. H. Voss. (*Stahl u. Eisen*, 1951, **71**, Sept. 27, 1037–1040). When choosing a steel for flame and induction hardening, consideration must be given to requirements for hardness and depth of case. Higher carbon contents permit the attainment of higher hardnesses and alloy additions increase the depth of hardness. The depths of hardening possible with normal steels are indicated; they are in general less than 6 mm. The materials employed in Germany for flame, induction, and immersion hardening are given. For special purposes a 0·7% C, 0·3% Mn steel is used; this is characterized by a small depth of hardening. Some Mn–V, Cr–V, and Cr–Ni–Mo steels are also employed.—J. P.

Recent Developments in Induction Heating for Thermal Treatments. J. Minssieux. (*Etudes Document. Mét.*, 1951, Apr.–May–June, 33–54). The principles of induction heating are stated, and the general advantages of this method of heating are indicated. Data on the frequencies employed are given and applications discussed.—T. E. D.

Application of Induction Heating to Production Heat-Treatment Processes. L. H. Williams. (*Metal Treatment and Drop Forg.*, 1951, **18**, Oct., 460–464). The author describes the use of induction-heating equipment in the treatment of motor-car components at the Banner Lane Works of the Standard Motor Company.—P. M. C.

Investigation on the Suitability of Steel and Cast Iron for Case-Hardening with High-Frequency Currents. F. Staub and K. Pogorecki. (*Prace Badawcze Glownego Inst. Met.*, 1951, **3**, No. 5, 375–387). [In Polish]. The results of investigations on the induction hardening of steel, steel castings, and cast iron are presented. The effect of surface temperature reached during heating on the hardness of the surface layer and the effect of the heating time on the depth of hardening are discussed. The mechanism of the transformations during high-frequency heating and their influence on the structure of the hardened zone are discussed.—V. G.

H.F. Induction Heating Is Economical. (*Machinist*, 1951, **95**, Nov. 3, 1657–1658). The article describes applications of high-frequency induction heating to soldering, brazing, and local hardening which the General Electric Co., Ltd., claim results in considerable savings.—E. C. S.

Economies Obtained with Induction Hardening. R. E. Van Dwenter and G. Bidigere. (*Machinery*, 1951, **79**, Aug. 16, 277–288). The Packard Motor Car Co. use induction heating for many selective surface-hardening operations. The advantages include short time required for heating; reduction in distortion; elimination of scale and decarburization; ability to harden specified surfaces without masking other surfaces; and uniformity of degree and pattern of hardness.—E. C. S.

Induction and Flame Hardening Simplified. J. Obrebski. (*Machinist*, 1951, **95**, Oct. 27, 1626–1627). A simple theory of heat input and heat extraction, which explains some hardening phenomena and shows why desired results are not always obtained, is set forth. The theory has been successfully applied by the Monarch Machine Tool Co. to the flame hardening of gears on a Gleason machine.—E. C. S.

Annealing and Tempering of Steel Bars in an Induction Heating Furnace Operating at the Supply Frequency. H. Krainer, M. Kroneis, and F. Raidl. (*Stahl u. Eisen*, 1951, **71**, Aug. 16, 880–888). Bars 20–80 mm. in dia. of eight steels containing 0·16–0·62% C, 0·3–1·4% Si, 0·5–1·0% Mn, 0–2·3% Cr, 0 or 0·12% Mo, 0–3·6% Ni, and 0 or 0·09% V were annealed or tempered in a 300-kW. Brown Boveri induction heating furnace operating at 50 cycles and 500 V., and subsequently subjected to tensile, notch-impact, and

hardness tests. Satisfactory annealing results were obtained for a very narrow diameter range, the efficiency reaching 70% for optimum bar dimensions and speeds of travel. Soft annealing, particularly of alloy steels, was not possible in the short treatment periods available. Excellent results are reported for tempering medium and high-strength steels.

Carbonitriding on the Increase Survey Shows. M. B. Bever, C. F. Floe and W. G. Zaruba. (*Iron Age*, 1951, **168**, Sept. 13, 151–155). A survey of the carbonitriding practice in America reveals that the process is being used in about 250 plants. A wide variety of parts is being treated, and the excellent surface wear resistance together with the possibility of substitution of carbon for alloy steels are among the advantages claimed.—A. M. F.

Steam Treatment Increases High-Speed Tool Life. H. Chase. (*Iron Age*, 1951, **168**, Sept. 20, 126–128). Steam at 15 lb./sq. in. in a furnace at 1025° F. produces a tightly adherent, hard oxide on cutters, drills, hobs, and other tools; it should not be more than 0·0001 in. thick. A great increase in production between regrinds is achieved.—A. M. F.

Rapid Tempering of High-Speed Steel. A. E. Powers and J. F. Libsch. (*Trans. Amer. Inst. Min. Met. Eng.*, 1951, 865–871; *J. Met.*, 1951, **3**, Oct.). The authors describe a study of rapid induction tempering of 6% W, 5% Mo, 4% Cr, 2% V high-speed steel, and show that the resulting mechanical properties are approximately equal to those obtained by conventional tempering.—G. F.

Increasing the Ductility of Tempered High-Speed Steel. E. I. Malinkina. (*Stanki i Instrument*, 1950, No. 2, 21–23). [In Russian]. The significance of additional tempering at 720° C. on the ductility and plasticity of high-speed steel was investigated using two steels with a sorbitic-type pearlitic structure. The main conclusions were: Additional tempering at 720–780° C. improves ductility and plasticity, heating for 2 hr. being sufficient; subsequent cooling must be rapid; with the normal tempering involving initial heating at 850–900° C., it is possible to obtain improved ductility and plasticity by rapid cooling after isothermal soaking at 720–740° C.; brittleness develops rapidly in the 550–600° C. range.—S. K.

FORGING, STAMPING, DRAWING, AND PRESSING

New Heavy Forge at Sheffield. (*Iron Coal Trades Rev.*, 1951, **163**, Nov. 16, 1075–1081: *Metal Ind.*, 1951, **79**, Nov. 9, 395–398. **The New Forge of Messrs. Hadfields, Limited.** (*Shipbuilder and Marine Engine-Builder*, 1951, **58**, Dec., 762–767). **New Heavy Forge.** (*Iron Steel*, 1951, **24**, Dec., 534–537, 559–561). **Heavy Forge Shop at Hadfields, Limited, Sheffield.** (*Engineer*, 1951, **192**, Nov. 9, 585–588: *Engineering*, 1951, **172**, Nov. 16, 616–619). **Hadfields' New Forge.** (*Brit. Steelmaker*, 1951, **17**, Dec., 632–646; *Overseas Eng.*, 1952, **25**, Feb., 235–237). **New Heavy Forge Unit.** (*Brit. Eng.*, 1952, **34**, Jan., 277–279). **New Plant for the Production of Heavy Steel Forgings.** (*Metallurgia*, 1951, **44**, Nov., 245–252).

Forging Practice. R. C. Benson. (*ESC News*, 1951, **5**, 3, 2–8). The length of a forging does not usually present the greatest difficulty but the distance between the columns of the press severely limits the width. Plant for manipulating the ingot, section changing, twisting, making eccentric and upsetting, and the production of hollow forgings are described.

Forging and Related Operations at the Buick Plant. P. H. Flynn and W. A. Koppi. (*Metal Treatment and Drop Forg.*, 1951, **18**, Oct., 433–439). The Company, located in Michigan, U.S.A., uses approximately 20 different grades of steel for the production of motor-car forgings. The chemical analysis and metallurgical control of these steels are discussed, and the uses of press and hammer forging are described.—P. M. C.

Preformed Billets Aid Forgings Production. (*Steel Processing*, 1951, **37**, Sept., 452, 453, 467). This is a brief appraisal of the die-rolling process for preforming billets for drop forging.

Forging Munition Shells. W. Trinks. (*Mech. Eng.*, 1951, **73**, Oct., 803–808). The paper is a review and evaluation of two earlier reports dealing with the steps required for making shell forgings from 74 to 240 mm. in dia.—D. H.

Note on the Influence of Forging Reduction on the Toughness of High-Speed Steel. G. Magliano. (*Met. Ital.*, 1951, **43**, Oct., 439–442). To obtain satisfactory core properties on high-speed steels, the metal has to undergo at least 80% forging reduction depending on the initial ingot size. The author discusses tests to study the possibility of reducing this figure. Round bars were reduced between 50 and 96% by forging. He found it was not possible to go much below 80%.—M. D. J. B.

The Care and Maintenance of Press Tools. W. M. Halliday. (*Sheet Metal Ind.*, 1948, vol. 25, Feb., pp. 351–353; Mar., pp. 549–554, 558; May, pp. 981–986; June, pp. 1175–1182; Aug., pp. 1592–1600; Dec., pp. 2421–2427; 1949, vol. 26, Mar., pp. 561–568; Apr., pp. 788–796; July, pp. 1481–1487; Nov., pp. 2385–2390; 1950, vol. 27, Mar., pp. 225–230, 238; May, pp. 423–426, 432; July, pp. 619–628; Oct., pp. 871–878, 883; 1951, vol. 28, Mar., pp. 257–263; Nov., 1015–1021). The disadvantages of an unplanned maintenance are outlined and a description is given of the application of a successful press-tool maintenance scheme suitable for both large and small works.—R. A. R.

High Production Methods for Nut Manufacture. (*Machinery*, 1951, **79**, Sept. 20, 487–490). A. P. Newall and Co., Ltd., Glasgow, operate cold-forging machines developed by the National Machine Co., Tiffin, Ohio, for producing hexagon nut blanks from round wire, ready for tapping, at very high speeds. Some machines are described.—E. C. S.

Problems and Progress in Manufacturing Bolts, Nuts and Rivets. W. E. Hill, jun. (*Wire and Wire Products*, 1951, **26**, Oct., 940, 982–986). The author surveys the origin and growth of the bolt, nut, and rivet industry, and its current problems. He believes that where difficulties arise they are due in equal measure to poor wire quality and faulty bolt-manufacturing methods.—J. G. W.

Maintenance and Improvement of Quality Cold Heading Wire. L. R. Franks and J. C. Harrigan. (*Wire and Wire Products*, 1951, **26**, Oct., 888–898, 998–999). Following an explanation of basic rules to apply in cold heading, the authors describe various faults arising from defective wire, and discuss the qualities of wire used in the Keystone Steel and Wire Company, Peoria, Illinois, for different types of fastener.—J. G. W.

Accurate Stampings Made at High Production Rates. H. Chase. (*Iron Age*, 1951, **168**, Sept. 13, 159–161). The production of torque converter shells, shrouds, and blades by stamping, at the Ford Cincinnati plant, are described. Very close tolerances are held and an unusual cam-operated punch is used for piercing blade slots in the shroud ring.—A. M. F.

Making High-Strength Seamless Tubing to Close Tolerances. L. A. Karg. (*Machinery*, 1951, **79**, Sept. 6, 418–422). The process, used by the Tube Reducing Corp. for the production of compression-formed seamless tubing, and known as the 'Rockrite cold-reducing process' is described. In bi-metal tubes, no bond other than that produced by pressure is used to join the two metals (usually copper and steel).—E. C. S.

Principles of Mass Production of Hollow Bodies by Hot Drawing. F. Drastík. (*Hutnik*, (Prague), 1951, **1**, No. 11, 246–248). [In Czech].

Putting the Squeeze on Steel. R. Cheney. (Steelways, 1951, **7**, Nov., 18–20). The application of cold extrusion to steel which was developed in Germany in 1935 is described. Phosphatizing the steel surface is essential to retain a surface film of lubricant during extrusion. The small amount of wasted metal (7% in the manufacture of 20-mm. shell cases) is a great advantage. Both alloy and plain carbon steels have been successfully cold extruded.—B. G. B.

Bar Extrusion. S. Geleji. (*Kohászati Lapok*, 1951, **6**, Sept., 197–200). [In Hungarian]. In contrast with the existing formulæ for calculating the forces involved in bar extrusion, which are unreliable for practical application, the author presents a new formula which accords reasonably well with experimental results.—L. W.

Profiles of Corrugating Dies: Calculation of Angles and Radii. J. H. Mort. (*Iron Steel*, 1951, **24**, Dec., 547–548). The author presents formulæ for the design of the profiles of dies used in press- or roller-type corrugating machines. It is suggested that the comparatively large discrepancies often found in corrugations could be lessened by general agreement on the size of the angle subtended by the corrugation arc and on the aggregate thickness of sheets simultaneously corrugated. The angle suggested is 106°, and for calculation purposes the aggregate thickness is taken as 0·075 in.—G. F.

Tri-Axially Measured Local Deformation in Deep Drawing and the Bulge Test. H. Güth. (*Technik*, 1951, **6**, Sept., 397–405). The author describes experiments in which he compared simple cup-drawing with the Erichsen type of bulge test by measuring the strains in all three directions.

The cup-drawing tests are also compared with similar experiments by H. W. Swift.—J. G. W.

Cold Drawing and Extrusion of Steel. (*Machinery*, 1951, **79**, Sept. 20, 498–499). Work on the application of phosphate coatings for cold drawing and extrusion of steel is being carried out by the Heintz Mfg. Co., and the Pennsylvania Salt Mfg. Co., Philadelphia, who have introduced the Pennsalt Foscoat process. The process covers cleaning, pickling, and application of the phosphate coating and a specially developed organic lubricant (Foslube) which reacts with the coating to produce a heat-resistant surface that has good adhesion under severe working conditions. The process is not intended for stainless and high-alloy steels. The English licencee is the Pyrene Co., Ltd., Brentford, who have developed Bonderite processes and Bonderlube lubricants.—E. C. S.

Investigations into the Ductility Characteristics of Cold Heading Steels. J. Billigmann. (*Stahl u. Eisen*, 1951, **71**, Aug. 2, 826–839). Tests on 13 plain carbon and low-alloy steel wires subjected to drafts of 0 to 30% show that their deformability depends on annealing conditions, and can be correlated with necking and the pearlite index, but not with other mechanical properties. The deformability of steels in subsequent cold heading decreases with drafts up to 15%, but increases again with larger area reductions. Whilst necking can be employed as a measure of cold-heading properties only in the case of steels subjected to identical area reductions, a high pearlite index is a reliable indication of good deformability. (30 references).—A. G.

Application of Logarithmic Strain Ratios to Tube Drawing. J. Tranier. (*Metal Treatment and Drop Forg.*, 1950, **17**, Spring Issue, 11–14: *Wire and Wire Products*, 1951, **26**, Apr., 312–314). The author outlines a graphical method for the rapid computation of a drafting programme and gives examples of its use.—J. G. W.

Drive Efficiency in Multiple Bar Drawing. F. Boehm. (*Stahl u. Eisen*, 1951, **71**, Aug. 2, 817–826). The various sources of power losses in multiple bar drawing have been investigated and related to the driving force and speed, and the number of bars. The most suitable plant dimensions and optimum operating conditions can be readily deduced from graphs reproduced in the text.—A. G.

The Effect of Die Profile on the Stress Distribution and Critical Deformations in Wire Drawing. E. Siebel. (*Stahl u. Eisen*, 1951, **71**, Aug. 2, 801–805). Theoretical considerations show that the stress distribution in a wire drawn through a die is parabolic with the maximum on the axis of the wire at the outlet of the die. This maximum stress can exceed the breaking strength of the material and cause rupture of the wire. Efforts should, therefore, be made to make the stress distribution as uniform as possible by suitable die design. A table summarizes optimum die parameters for a 10-stage drawing process, account having been taken of A. Pomp and W. Knackstedt's data on work-hardening properties of 0·03% C steel wire (*see J. Iron Steel Inst.*, 1928, **118**, 400).—A. G.

Some Principles of Continuous Wire Drawing. C. Blazey and V. W. Benjamin. (*Wire and Wire Products*, 1951, **26**, Sept.. 751–757, 798). The authors describe a graphical method for computing drafting programmes for continuous wire-drawing machines of the tandem or slip-cone type. The reasons for slip of the wire on the capstans are analysed.

New Methods and Devices for the Drawing Die Shop. W. Lueg. (*Wire and Wire Products*, 1951, **26**, Dec., 1146–1148). Two instruments for checking the taper and the parallel length of the wire-drawing die respectively, have recently been developed at the Max-Planck-Institut, Düsseldorf, and are described. The former, named 'Alfameter,' is an optical instrument; the latter, named 'Zetmeter,' is a mechanical one.—J. G. W.

ROLLING-MILL PRACTICE

A Critical Review of Various Theories of Rolling. Z. Wusatowski. (*Prace Badawcze Glownego Inst. Met.*, 1951, **3**, No. 5, 389–416). [In Polish]. The author reviews recent theories of the rolling process. In the first part the coefficient of friction is discussed. Recent theories consider this factor as varying along the arc of metal-roll contact, but so far no theory has been fully satisfactory. In the second part the theories of Nadai, Tselikov, and Orowan are reviewed. Finally the author analyses the shortcomings of the theoretical assumptions concerned in all theories of rolling.—V. G.

On Rolling Friction. V—Influence of Surface Roughness. T. Hisada and K. Tsugawa. (*J. Mech. Lab.*, 1950, **4**, No. 1, 4–6). [In Japanese]. Rolling friction increases rapidly with increasing roughness of the surfaces in contact. When the roughness is smaller than 1μ, a previously derived formula concerning the frictional moment remains valid, but when the roughness is greater, the influence of the roughness becomes predominant.—T. E. D.

Pressure Distribution Between Stock and Rolls in Hot and Cold Flat Rolling. C. L. Smith, F. H. Scott, and W. Sylwestrowicz. (*J. Iron Steel Inst.*, 1952, **170**, Apr., 347–359). [This issue].

Comparisons between British and American Rolling-Mill Practice. G. Foster. (*Iron Coal Trades Rev.*, 1951, **163**, Dec. 7, 1235–1242). The author presents a detailed review of American rolling-mill practice and compares it with British practice. The American attention to simplification, standardization, and maximum productivity is discussed, and some suggestions for improvements in British practice are given.

Use of Non-Destructive Testing Methods in the Rolling Mill. W. Jellinghaus and H. Möller. (*Stahl u. Eisen*, 1951, **71**, Sept. 13, 995–1002). The principles and mode of application of different methods of non-destructive testing are described. For ingots and slabs, the ultrasonic method is most reliable and the Firestone instrument is discussed. Trost's method depends on the defect reflecting ultrasonic vibrations, so a defect in a slab causes a reduction in transmitted intensity. It is claimed that ultrasonics can be used to differentiate between fine- and coarse-grained steels. For determining the thickness of hot- and cold-rolled strip, the X-ray absorption method has proved of great value, the Westinghouse and General Electric equipment being described. The Baldwin Instrument Co. has developed an apparatus for the continuous recording of pass reduction which can detect variations in reduction of 0·1%. Pohlmann's ultrasonic 'camera' for detecting flaws is illustrated. The oscilloscope method can be used for testing welds if the vibrations are obliquely incident. Methods are available for detecting watt losses on whole sheets of transformer iron.—J. P.

Automatic Control of Various Operations in the Iron and Steel Industry. A. B. Chelyustkin and B. A. Levitansky. (*Iron Steel Inst. Translation Series*, 1952, No. 430). This is an English translation of a paper which appeared in *Bányászati és Kohászati Lapok*, 1950, **5**, Dec., 700–704 (*see J. Iron Steel Inst.*, 1951, **169**, Sept., 64).

Rapid Reversal Technique Applicable for Rolling Mills. J. Rabinow. (*Steel*, 1951, **129**, Nov. 12, 97–98). Small electric motors can be reversed in 0·003–0·004 sec. by converting the energy of the rotor into potential energy in a spring instead of dissipating it as heat in a brake during deceleration. This energy is then used to accelerate the rotor rapidly in the opposite direction. It is suggested that this method of using a stored-energy device might be used in the reversal of two-high mills.—A. M. F.

Advantages and Application of Small-Diameter Work Rolls in Wire Mills. A. Makomaski. (*Hutnik*, 1951, **18**, Sept., 358–362). [In Polish]. The main types of continuous rolling mill for the production of wire are briefly described. The conditions of elongation of the material, its dependence on spread and the 'coefficient of efficiency' in the rolling process are outlined. The unsuitability of rolls of 200 mm. in dia. for the final pass in wire rolling, and advantages of rolls 100 mm. in dia. are discussed.—V. G.

Increasing Output of Steel Wire Rods. (*Wire Industry*, 1951, **18**, Nov., 980–981). The new Guest, Keen and Nettlefolds (South Wales) Ltd., continuous rod mill at Cardiff is described and illustrated. The minimum design output is 230 tons/shift with rod size ranging from 5 S.W.G. to 1¼ in. dia. J. G. W.

Blooming Mills: Requirements for Electrical Equipment. G. G. Nicholson. (*Elect. Rev.*, 1951, vol. 149, Oct. 5, 665–669: *Iron Steel*, 1951, **24**, Oct., 448–453). The author considers the requirements of electrical equipment for blooming mills and their auxiliary equipment. The driving motors of the main mill are discussed in some detail. The electrical equipment associated with the main tables, breast rollers, manipulators, screwdown gear, the ingot bogie and other lighter-duty auxiliaries, and the bloom shears being dealt with in turn. The Ward-Leonard control system and its advantages and disadvantages are described.—G. F.

Keeping Clean the Rolls in Hot-Rolling Sheet Mill Stands. W. Krämer. (*Stahl u. Eisen*, 1951, **71**, Aug. 16, 878–880). Adhesion of steel particles to the surfaces of the rolls is due to defects in the hardened roll surfaces, generally resulting from usage, and to faulty drive conditions which can be improved by reducing play on intermediate shafts and drive of the upper roll. Three arrangements of automatic roll-grinding devices are described and illustrated.—A. G.

The New Sheet Mills of the Société Anonyme d'Espérance-Longdoz. F. de Bassompierre. (*Ossature Métallique*, 1951, **16**, Oct., 466–472). A description is given of the new semi-continuous strip mill at Jemeppe on the Meuse.—P. F.

Steel Strip Manufacture from Iron Powder. (*Hutnik*, (Prague), 1951, **1**, No. 3, 57). [In Czech]. The production of iron and steel strip from powder of about 0·01-in. dia. particles is described. A belt made from the compressed powder is electrically heated to 1400° C. while passing through the rollers which act as electrodes. The final material compares favourably with similar strip made by conventional methods. The possibility of thus producing steel harder inside than on the surface is mentioned, and some implications, such as the production of self-sharpening knives, plough shares, and the magnetic properties are discussed.—P. F.

Steel Warehouse Installs Cold Reduction Strip Mill. (*Steel*, 1951, **129**, Nov. 12, 90–92). A Chicago warehouse has been equipped to reroll 2000 tons of strip steel per month to customers' specifications. Facilities consist of a two-high 700-h.p. 3-stand 16-in. tandem cold-reducing mill, and bright-annealing equipment for strip and for wire. This new rolling capacity will supplement regular supplies and produce steel to standard as well as to intermediate tempers and tolerances.

MACHINERY FOR IRON AND STEEL PLANT

Ore Winning at Corby—Installation of World's Largest Walking Dragline. (*Iron Steel*, 1951, **24**, Dec., 543–544). **World's Largest Walking Dragline.** (*Brit. Steelmaker*, 1951, **17**, Dec., 654–658 : *Welding Met. Fab.*, 1951, **19**, Dec., 467–473 : *Brit. Eng.*, 1952, **34**, Jan., 270–276 : *Metallurgia*, 1951, **44**, Nov., 227–231). **The W.1400 Walking Dragline.** (*Overseas Eng.*, 1952, **25**, Jan., 205–209).

Pump Design and Application in Iron and Steel Works. C. G. Evans. (*J. Iron. Steel Inst.*, 1950, **170**, Apr., 360–374). [This issue].

Inspection in Heavy Engineering. M. A. Fiennes. (*Eng. Insp.*, 1951, **15**, Summer, 64–77). The author describes typical rolling mills and forging presses which are the main products of the Davy-United Engineering Co., Ltd. The organization necessary to produce such massive machinery is outlined.—P. M. C.

WELDING AND FLAME-CUTTING

Resistance Variations During Spot Welding. W. L. Roberts. (*Welding J.*, 1951, **30**, Nov., 1004–1019). A survey is made of resistance variations encountered in the formation of spot welds at 60 cycles/sec. Techniques are described for the measurement of resistance.—U. E.

The Inert-Arc Welding of Thin-Walled Tubing. R. S. Zeno and H. L. S. Leslie. (*Welding J.*, 1951, **30**, Nov., 986–992). Factors influencing the inert-arc welding of thin-walled tubing were investigated. The tubing was made of stainless steel, mild steel, nickel, titanium, molybdenum, and Fernico. Argon was preferred to helium with stainless steel type 347.—U. E.

The Arc Welding of Carbon-Molybdenum Steel Pipe. F. J. Winsor. (*Welding J.*, 1951, **30**, Sept., 817–827). The effects of preheating and/or stress-relieving on the properties of welds in 0·5% Mo steel pipe ($\frac{9}{16}$-in. wall), furnace tubing ($\frac{13}{16}$-in. wall), and flange stock ($\frac{3}{4}$ in. thick) were investigated. For service temperatures above 800° F., preheating and stress relieving should not be required for welds made with cellulose-coated electrodes in certain molybdenum steels in thicknesses up to at least $\frac{3}{4}$ in. The free-bend test of welding procedure was of questionable value.—U. E.

Aircomatic Welding of Austenitic Stainless Steels. W. G. Benz, jun., and J. S. Sohn. (*Welding J.*, 1951, **30**, Oct., 911–926). An investigation of mechanical properties and resistance to corrosion of austenitic stainless-steel weld metal and welded joints deposited with the inert-gas-shielded metal-arc process is reported. The tensile strength of weld metal deposited with 19% Cr, 9% Ni filler rods is at least 80,000 lb./sq. in. with elongations of 40–50%. Transverse guided-bend test bars withstood bending to 180°. The 'Huey' corrosion resistance of austenitic weld deposits in the stress-relieved and in the stabilized conditions is equal to or greater than the corrosion resistance of similar types of plate metal when subjected to the same thermal treatments.—U. E.

Automatic Welding in Steel Plant Maintenance. W. P. Hoffman. (Amer. Welding Soc. : *Blast Furn. Steel Plant*, 1951, **39**, Nov., 1348–1353). The adoption of submerged-melt welding for steelworks maintenance has enlarged the scope of operations of the welding shop and resulted in appreciable savings in mill operation. A new welded base for a 40-in. blooming-mill manipulator drive, repairs to a 32-in. manipulator ram, servicing a 14-in. mill pinion and mill-drive spindle, and welding in ingot mould bogie construction are discussed.

Deep Welding—A New Method of Oxy-Acetylene Welding. R. Gunnert. (*Metal Progress*, 1951, **60**, Oct., 104–107). This method calls for a deep, high-pressure, and concentrated flame, directed at right angles to the length of the joint ; it also requires a butt joint, *i.e.*, plate edges are not bevelled. Welding speed can be increased by 50% and the consumption of welding rod and gases is lowered.—J. P. S.

Nested Electrodes for Metal-Arc Welding. W. A. Snyder. (*Welding J.*, 1951, **30**, Nov., 557s–564s). The nested electrode consists of two or more metal filler rods nested together but insulated from each other except at the end where they are gripped by the electrode holder ; at this point they are connected to each other or to a common source of current. Satisfactory welds were produced from these electrode nests.

Filler Materials for Welding Plain Carbon and Low-Alloy Structural Steels. W. Hummitzsch and F. Rapatz. (*Stahl u. Eisen*, 1951, **71**, Aug. 30, 925–940). The physical, chemical, and mechanical properties of bare, flux-cored, and coated electrodes for arc welding plain carbon and low-alloy structural steels are discussed. The effects on welding and properties of welds of various constituents of electrode coatings are outlined. (35 references).—A. G.

Some Recent Developments in Semi-Hard Steels for Welded Structures. C. Fornaci. (*Ossature Métallique*, 1951, **16**, Dec., 603–607). New steels developed by the Terni Company for purposes involving welding as well as prestressing and autofrettage are described. Yield strengths at 100° C. are about 26 tons/sq. in., tensile strengths 32 tons/sq. in., and elongations 20%. The steels are of the low-alloy Mn–Cr or Mn–Cr–Cu types.—P. F.

Ice-Flower-Like Structure in Metal Deposited by Arc Welding in Particular Mild Steel. M. Okada and Y. Wakabayashi. (*Welding J.*, 1951, **30**, Sept., 469s, 472s). Relationships between arc atmosphere and dissolved hydrogen and FeO and hydrogen in molten steel are calculated. Hydrogen determinations are given for weld metal deposited from many electrodes, including gas-shielded and low-hydrogen types. U. E.

Residual Stresses in Welded Mild Steel Pipe. L. J. Privoznik. (*Welding J.*, 1951, **30**, Sept., 422s–428s). Stresses due to circumferential single-**V** butt welds made with five passes in 5½-in. dia., ½-in. wall mild-steel pipe, were determined by the boring-out method. Transverse stresses in the weld were tensile at the inner surface and compressive at the outer surface, with the maximum compressive stresses occurring a short distance below the outer surface. Stress relieving at 1200° F. for 1 hr. reduced the magnitude of the transverse stresses from 30,000 to 10,000 lb./sq. in. max. Circumferential stresses were less than 11,000 lb./sq. in. compressive at or near the inner surface and tensile at or near the outer surface. Stress relieving the welded as-received pipe did not affect the circumferential stresses. Annealing the pipe before welding resulted in circumferential stresses higher than in the welded as-received pipe.—U. E.

An Investigation of the Criteria of Weldability of Thin Low-Carbon Steel Plates. (*Lastechn.*, 1951, **17**, Nov., 163–179). [In Dutch]. The object of the investigations was to find the best method of determining weldability. The methods were divided into two classes : (*a*) Those in which the variables are limited to the properties of the plate material, excluding all other factors which, in practice, affect weldability ; and (*b*) those where as many factors as possible are considered. Under (*a*), the following tests are considered : single and multi-run Focke-Wulf ; Eisenkolb indentation method ; under (*b*) the Zeyen fillet weld test ; the cross test ; and the van Muller butt-bend test. The relative suitability of the local fusion test and of the indentation test for thin sheets up to 1·7 mm. in 0·12% C steel is discussed.—R. S.

Investigation of Factors which Determine the Performance of Weldments. C. E. Hartbower and W. S. Pellini. (*Welding J.*, **30**, Oct., 499s–511s). The explosion bulge technique has been applied to study the fracture of ¾-in. butt welds and unwelded plate. The performance of pearlitic steel welds is determined by the weld rather than by the heat-affected zone. The significance of explosion bulge test evaluations in terms of structural performance is discussed.—U. E.

The Bonding of Metals. C. J. Moss. (*J. B'ham Met. Soc.*, 1951, **31**, Sept., 149–161). After some remarks on the nature of adhesion the author describes the nature and uses of Redux and Araldite, two synthetic resin adhesives extensively used to bond metals.—J. B. B.

Productivity Report on Welding. (*Anglo-American Report on Productivity*, 1951). This 56-page report, with 27 plates, describes what was observed by a British team of welding specialists which visited the U.S.A. in 1950, and reports their conclusions. Their recommendations include that: (1) Managements should devote serious thought to economic planning and the more generous introduction of mechanical handling devices. (2) Unsparing efforts be made to provide more goods, particularly foodstuffs, available in retail shops so that it is manifest that hard-earned money is worth the effort. (3) Where more than one union operates in a factory there should be closer co-operation between shop stewards.

Weld that Defective Casting. (*Canad. Metals*, 1951, **14**, July, 24–26, 28). Recovery of defective castings can be achieved by proper use of repair welding, and suitable welding techniques are described and discussed for various metals. Machinability and serviceability of the casting need not be impaired.—E. C.

Cleaning Castings by Oxy-Acetylene. (*Canad. Metals*, 1951, **14**, July, 23). The cleaning of castings by an oxy-acetylene flame into which an iron-rich powder is injected is described (*see* 'Powder Washing Process Ready,' *J. Iron Steel Inst.*, 1951, 170, Jan., 74).

Powder Cutting Handles Stainless with Ease. (*Steel*, 1951, **129**, Nov. 5, 94–96). **Powder Processes; A New Industrial Tool.** A. B. Kinzel, D. Swan, H. Biers, and H. R. Pufahl. (*Trans. Inst. Welding*, 1951, **14**, Oct., 154–160). Powder-cutting and scarfing processes are now applied to the severing and forming of non-ferrous materials, cast iron, refractory materials, and reclamation of castings.—U. E.

Powder Cutting of Cast Iron with Oxy-Acetylene. (*Australian Foundry Trade J.*, 1951, **2**, July 3, 4). The oxy-cutting process as applied to the cast-iron series of materials has, in the past, always presented difficulties due to the amount of graphite present. This article describes a new process in which finely divided iron-rich powder is introduced into a conventional oxy-acetylene cutting stream, thereby reducing the effective carbon content of the molten material.—P. M. C.

MACHINING AND MACHINABILITY

Technological Accuracy and Fineness of Machining. A. A. Matalin. (*Stanki i Instrument*, 1949, No. 7, 19–22). [In Russian]. An account is given of profilographic investigations of the surface finish of steel and non-ferrous metal specimens after being subjected to various machining processes.—S. K.

Mechanism of Plastic Deformation during the Machining of Steel. S. F. Glebov. (*Stanki i Iustrument*, 1949, No. 7, 8–11). [In Russian]. Present views on the mechanism of plastic deformation during the cutting of steel are considered, and experiments are described in which photographs were obtained of the cutting of a polished and etched steel plate.

Investigation of Surface Quality in Drilling and Reamering. M. O. Yakobson. (*Stanki i Instrument*, 1949, No. 4, 18–20). [In Russian]. The factors influencing the quality of the fine surface of drilled and reamered holes are considered, and the results are given of experiments which showed that the actual micro-unevenness of such surfaces is 20 to 30 times greater than calculated.—S. K.

Effect of Structure on Machinability Demonstrated. N. Zlatin and L. Nowikowski. (*Iron Age*, 1951, **168**, Aug. 2, 95–98). Investigations with American Iron and Steel Institute steels 3140, 4140, and 8640 in annealed, quenched and tempered, and resulphurized states show that structure is a better criterion of machinability than chemical composition. The annealed samples were treated to give a structure of essentially 75% pearlite and 25% ferrite, the tempered samples were for a hardness of 300 Brinell. Machining tests were carried out with both high-speed steel and carbide tools; differences in structure had less effect with the latter. Resulphurizing to 0·1% improved machinability.—A. M. F.

High-Speed Cutting of 30KhGSA Steel. M. A. Makhatadze. (*Stanki i Instrument*, 1950, No. 2, 14–15). [In Russian]. The author reports experiments on the high-speed turning of a high-quality alloy steel, carried out with special reference to the influence of cutting factors on the quality of the surface produced.—S. K.

High-Speed Cutting in the Machining of Wheel Centres. L. B. Gofman and E. N. Kanevskii. (*Stanki i Instrument*, 1950, No. 3, 18–19). [In Russian]. A high-speed boring method is described which, carried out without cooling, secures a quality of surface satisfactory for wheel centres.

The Sharpness of the Cutting Edge of a Tool and the Quality of the Surface. P. E. D'yachenko. (*Stank i Instrument*, 1950, No. 2, 19–20). [In Russian]. A metallographic investigation was made of the effect of the sharpness of tool edges on the smoothness and hardness of the surface of steel specimens, of various initial structures, externally broached under standard conditions.—S. K.

Measurement of the Waviness of a Machined Surface. P. E. D'yachenko and V. E. Vainshtein. (*Stanki i Instrument*, 1950, No. 1, 15–16). [In Russian]. The use of profilographs for measuring simultaneously the height and length of the undulations on machined plane, cylindrical, and shaped surfaces is discussed. Examples are given of profilograms obtained with a Levin and a modified Ammon profilograph. An equation for choosing the most suitable probe-sphere size for a given surface is presented.—S. K.

Hard-Facing a Tool with High-Speed Steel. I. M. Erofeev. (*Stanki i Instrument*, 1949, No. 8, pp. 18–20). [In Russian]. Techniques for hard-facing, with the aid of oxy-acetylene welding, of large cutting tools, milling cutters, and broaches with high-speed steel are described.—S. K.

Envelope Milling—A New Method of Machining Solids of Revolution. S. A. Rozenburg. (*Stanki i Instrument*, 1950, No. 1, 3–6). [In Russian]. A description is given of the process of milling with internally toothed circular milling cutters rotating eccentrically to the rotating work. Detailed consideration is given to the superior quality of surface finish obtained. This method results in productivities 5–7 times greater than those corresponding to normal external milling under comparable conditions.—S. K.

Surface Quality in Broaching. P. E. D'yachenko and A. P. Dobychina. (*Stanki i Instrument*, 1950, No. 3, 12–14). [In Russian]. The factors influencing the quality of a surface produced by broaching are considered. The distribution of plastic deformation during the broaching of a specimen of normalized steel is illustrated and graphs are given showing the dependence of surface roughness on cutting conditions for this specimen, as well as for those with lamellar pearlitic, granular pearlitic, and sorbitic structures, respectively.—S. K.

Surface Finish Measurement. C. Timms and C. A. Scoles. (*Metal Treatment and Drop Forg.*, 1951, **18**, Oct., 450–454). A Talysurf, model 2, stylus instrument was modified to enable surface finish records to be obtained with a vertical magnification of 100,000 and a horizontal magnification of 2000. Records obtained with it are compared with those obtained with a Zeiss-Linnik interference microscope. They are in very good agreement.—P. M. C.

Machining Crankshafts for Consul and Zephyr Cars. (*Machinery*, 1951, **79**, Dec. 20, 1059–1069; Dec. 27, 1117–1121). The methods employed on the new production line at Dagenham works of the Ford Motor Co., Ltd., are described.—R. A. R.

Method X. F. M. Campbell. (*Steelways*, 1951, **7**, Nov., 28–29). When a spark is made to jump from a brass electrode to a piece of metal immersed in a non-conducting coolant a depression is formed in the metal. This principle has been applied to the drilling of holes in tungsten carbide and hard-alloy steels. No distortion of the metal by heat occurs and accuracies of 0·0005 in. are claimed. Threads and unusual shapes have been successfully cut in the hardest alloys.

Automatic Grinder Cuts Stainless Conditioning Costs. W. G. Patton. (*Iron Age*, 1951, **168**, Sept. 27, 90–91). A new grinding machine moving on tracks parallel to the slab is used by the Rotary Electric Co., Detroit, for conditioning stainless-steel slabs. The machine is hydraulically controlled and, compared with the old type of swing grinder, is more economical, safer, and reduces the physical effort required.—A. M. F.

CLEANING AND PICKLING

The Descaling of Stainless Steels. G. Rossi-Landi. (*Mét. Constr. Mécan.*, 1951, Oct., **83**, 763–765). Factors affecting the descaling of austenitic, martensitic, and ferritic stainless steels are mentioned. The use of inhibitors, accelerators, and other additions to the pickling bath are noted.—R. S.

Patenting with Continuous Cleaning and Coating. C. H. Williams, jun. (*Wire and Wire Products*, 1951, **26**, Oct., 881–883). The author describes a plant at the Pittsburgh Steel Co., Monessen, Pa., which has recently passed the experimental stage into production. It is 275 ft. long and consists of reel space, a 40-ft. air-patenting furnace, two lead quench pans (8 and 15 ft.), scale breaker, acid cleaning tub, water bath and rinse, borax coating tank, and 30-block take-off frame. The plant deals with 0·115-in. dia. tyre bead wire, and is operated at 30 ft./min.—J. G. W.

Depolarizing Agents and Their Effects and Savings in Cleaning of Rods and Wire. J. T. Irwin. (*Wire and Wire Products*, 1951, **26**, Oct., 899–901, 994–996). Having explained cathodic polarization the author gives an account of investigations and development work by Azed Inc., Waukegan, Illinois, on metallo-organic depolarizing agents. Saving of acid, shorter pickling times, and smoother surfaces are reported.—J. G. W.

A Progress Report on the Development of the Wheelabrator Mechanical Cleaning Process. G. D. Dill. (*Wire and Wire Products*, 1951, **26**, Oct., 910–913, 992–993). The Wheelabrator process employs centrifugal force to propel steel shot at 400 lb./min. from a 19½ in. dia. × 2½ in. wide wheel with a velocity of about 12,000 ft./min. The equipment has been installed in several wire plants with good results.—J. G. W.

Economizing Compressed Air in Sand-Blasting. A. Václavovič. (*Hutník*, (Prague), 1951, **1**, No. 5, 111–112). [In Czech]. An invention relating to sintered carbide liners on the inner walls of sand-blasting nozzles is mentioned and its efficiency analysed. A saving of about 40% of compressed air is achieved, in comparison with unprotected nozzles.—P. F.

New Wet Blast Machine Designed Through Field Research. E. E. Brodhag. (*Metal Treating*, 1951, **11**, Sept.–Oct., 4, 5). The sand-blasting machine and its capabilities are briefly outlined. Very small size silica-type abrasive (80 to 2500 mesh) can be used, thus enabling tolerances of 0·0001 in. to be maintained.—P. M. C.

Preparation of Metallic Surfaces before Painting. J. Frasch. (*PACT*, 1951, June, 211–212; Aug., 284–287). Before painting metals, three operations should be carried out, namely, degreasing, descaling, and passivation. Degreasing is effected with organic solvents or alkaline solutions, whilst acid solutions are generally used for descaling. Here it is suggested that 'Framanol,' a complex solution of phosphates of chromium and of polyamines should be used to effect the two operations, and also to render the surface passive. Passivation can also be carried out with a solution of dichromate of zinc and/or manganese with a gelatine base. Particular reference is made to the treatment of aluminium and steel surfaces.—T. E. D.

PROTECTIVE COATINGS

The Influence of Ultrasonics on Electrolytic Processes. V. A. Roll. (*Z. Metallkunde*, 1951, **42**, Sept., 271–273). Continuation of a series of articles (*see J. Iron Steel Inst.*, 1951, **169**, Dec., 412). The surfaces, crystal sizes, textures, and microhardnesses of metal layers deposited electrolytically while under the influence of supersonic vibrations were examined. Nickel and silver were used. The surfaces were not appreciably influenced, except for a reduction in deposition rate.—P. F.

Hot Hardness of Plated Finishes Measured. (*Iron Age*, 1951, **168**, Sept. 20, 119). The National Bureau of Standards has developed a diamond indenter using very low loads for measuring the hot hardness of electrodeposits. To eliminate oxide films, specimens are heated and tested in an inert gas atmosphere.—A. M. F.

A Proposed Method for the Control of Hard-Chromium Baths. (*Metalloberfläche*, 1950, B, **2**, July, 105–106). It is suggested that instead of taking samples for analysis from a bath at fixed time intervals, this should be done after each 1% of the available chromium (calculated by measuring the current passed through the bath) has been deposited.—O. H. G.

The 'Onera' Bright Chromizing Process. B. Jousset. (*Metal Progress*, 1951, **60**, Oct., 76–77). Perfectly regular, smooth, and bright layers are obtained in a single operation with the new chromizing process patented at the Office National d'Etudes et de Recherches Aeronautique (ONERA). In this process gaseous chromium fluoride decomposes or 'cracks' at the surface of the steel, the chromium diffuses into the metal, and the hydrofluoric acid recombines with chromium chips that are packed in with the parts. The fields of application are discussed.—J. P. S.

Alloyed Chromised Coatings. (*Product Finishing*, 1951, **4**, Apr., 58–59). The properties and resistance to corrosion of cementation coatings of chromium–aluminium, chromium–silicon, and chromium–zirconium are briefly discussed.—J. P.

Hard Chromium Plating of Large Cast Iron Drum-Drier Rolls. A. W. Wallbank and G. W. Airey. (*J. Electrodep. Tech. Soc.*, 1951, **27**, Advance Copy No. 8, 1–6). The method is described by which cast-iron rolls 4 ft. in dia. and 10 ft. long were successfully plated with chromium. (*See* "Chromium Plating of Large Drying Cylinders," *J. Iron Steel Inst.*, 1951, **169**, Sept., 80).—J. P.

Recovery of Chromic Acid from Plating Rinse Waters. E. W. Neben and W. F. Swanton. (*Plating*, 1951, **38**, May, 457–460, 470). Economic aspects of recovery of chromic acid by vacuum evaporation from plating rinse waters with the aid of the Pfaudler package unit, consisting of glass-lined and stainless-steel equipment, are discussed.—A. G.

Experiments in Chromium Plating from Non-Aqueous Media. A. L. Hanson, D. Frokjer, and D. Mitchell. (*Metal Finishing*, 1951, **49**, Apr., 48, 49, 69). Experiments have been carried out on plating chromium from solutions of chromic chloride and acetate, chromic acid and potassium dichromate in fused acetamide, acetamide–urea mixtures, formamide, acetic acid, ethanolamine, acetonitrile, and dimethylformamide. The best deposits were obtained in the first three solvents, but even these did not appear to be completely satisfactory. Additions of H_2SO_4 increased the conductivity but did not affect the plating results when using trivalent chromium; with hexavalent chromium, H_2SO_4 improved the results somewhat.—J. P.

Electrodeposition in Marine Engineering. R. E. Wilson. (*Metal Ind.*, 1951, **79**, Aug. 31, 171–174; Sept. 14, 221–223). The author discusses the application of electrodeposited nickel and chromium to provide corrosion and wear resistance respectively. The reclamation of worn parts and the treatment of new ones are considered. Special reference is made to marine engine crankshafts, cylinder bores and liners, turbine glands, and press rams.—P. M. C.

Choose the Right Nickel Plating System. (*Steel*, 1951, **128**, June 4, 94–96; 117–132). This article describes many applications of nickel plating and discusses the relative merits of the following processes: (1) High and low *p*H Watts baths; (2) all-chloride nickel bath; (3) chloride–sulphate bath; (4) Land nickel plating bath; (5) barrel plating technique; and (6) special purpose baths. Consideration is given to the mechanical properties of the coating and techniques of cleaning.—M. D. J. B.

Influence of Anode Shape on the Uniformity of Nickel Coatings in Electroplating. D. Mojert. (*Metall*, 1951, **5**, Sept., 388–392). Experiments, in which iron plates of standard size were nickel-plated under constant potential, *p*H value, and concentration and temperature of the bath, show that the plating thickness is much more uniform with grid anodes than with solid plate anodes. The converse holds true for the plating of perforated sheets. It was also confirmed that greater current densities are possible with perforated or grid anodes.—J. G. W.

The Effect of Copper Undercoats on the Protective Value of Nickel–Chromium Coatings on Steel. B. B. Knapp and W. A. Wesley. (*Plating*, 1951, **38**, Jan., 36–38, 45–48, 53–56). Extensive corrosion tests on high-carbon steel panels plated with nickel plus chromium, and copper plus nickel plus chromium coatings show that coatings with thick copper undercoats are inferior to copper-free coatings of equal thickness, partly owing to the corrosive action of copper corrosion products on chromium–nickel coatings. After an initial beneficial effect, thin copper undercoats were also found to accelerate the atmospheric corrosion of nickel.—A. G.

Methods for Testing Thickness of Electrodeposits. II. Comparison of Methods for Nickel on Steel. H. J. Read and F. R.

Lorenz. (*Plating*, 1951, **38**, Mar., 255–263). The reproducibility of the Magne-gauge, the BNF jet test, the microscopic method, and the stripping method have been found to be satisfactory, and the absolute thickness values sufficiently accurate if the proper calibrations are used. The microscopic method with a magnification of 500 should not, however, be used for deposits of less than 12·5 μ. (5 references).—A. G.

Electrodeposition of Nickel in the Bores of Tubes Using Insoluble Anodes. A. W. Hothersall and G. E. Gardam. (*J. Electrodep. Tech. Soc.*, 1951, **27**, Advance Copy No. 7). Smooth deposits of nickel having good mechanical properties may be built up to a considerable thickness on the bores of tubes by using an insoluble anode made of or coated with lead. A nickel-sulphate/boric-acid solution free from chloride is circulated through the tube and its composition is maintained, by the continuous or periodic addition of nickel hydroxide, in a finely divided condition.—J. P.

Electroplating Aids in Clad Steel Production. S. E. Sangster. (*Products Finishing*, 1951, **15**, June, 12–16). A layer of nickel 0·005-in. thick is electroplated on one face of sheets of stainless steel or Inconel before these are placed on carbon or low-alloy steel slabs, the surfaces of which have been grit-blasted, to be rolled down to produce clad steel sheet. The nickel, being soluble in steel, gives good adhesion and also serves as a barrier to prevent carbon from migrating from the carbon steel into the corrosion-resistant cladding.—J. P.

Hot-Dip Galvanizing and the Supply of Zinc. A. Gordet. (*Mét. Constr. Mécan.*, 1951, **83**, Jan., 53–55; Feb., 123–125; Mar., 197–199; Apr., 297–299; May, 387, 389). Two methods of surmounting the zinc shortage are the refining of scrap metals and the direct charging of scrap metal. The question of using remelted zinc is discussed. The importance of using sufficiently large vats in wire galvanizing, and the use of pure zinc, keeping iron contamination at a minimum, are stressed. The author feels that the lead content should be slightly over the 1·6% specified in America. The effects of aluminium up to 0·2% are discussed. Lead is not harmful and, indeed, 1% is beneficial in galvanizing zincs. Whilst lead and aluminium can be tolerated in remelted zinc, iron, antimony, cadmium, and copper must be strictly controlled.

Hot-Dip Wire-Galvanizing Installation in Manchester. (*Engineering*, 1951, **172**, Nov. 2, 556–557). **Hot Dip Galvanized Wire Plant.** (*Metal Ind.*, 1951, **79**, Oct. 26, 364, 365). A brief account of the new plant at the Manchester works of Richard Johnson and Nephew, Ltd., is given. There are 11 lines each comprising lead bath, pickling plant, zinc bath, and winding frame. Production is 1500 tons/week.—P. M. C.

"Inner Surfaces" in Hot-Dip Galvanizing. H. Bablik. (*Metall*, 1951, **5**, Nov., 479–480). The author points out that the reaction rate between iron and zinc is known to be determined by the size of the phase-boundary surface between the two; he develops the idea that this surface is increased not only by inclusions and by graphite in cast iron, but also by polishing or rolling.—J. G. W.

Outlook for Continuous Galvanizing Lines in U.S.A. E. A. Matteson. (*Products Finishing*, 1951, **15**, July, 64). Approximately half of all galvanized sheet made in U.S.A. will soon be made by continuous strip methods. The quality of coating, both from adherence and corrosion standpoints, is superior to any coating produced by older methods. For this reason alone continuous strip galvanizing should replace all other types of sheet galvanizing. Elimination of heavily coated front edges saves zinc, and operating costs can be lower than in sheet galvanizing.—J. P.

Modern Practice in Hot Dip Galvanising. R. W. Bailey. (*Electroplating*, 1951, **4**, Sept., 277–280). Reactions occurring in the galvanizing kettle and on the surface of steel leading to the formation of dross are described briefly and methods mentioned for minimizing them. The effect of alloy layers on ductility of galvanized coatings is discussed and a brief description of the Sendzimir process is given.—J. P.

The Problem of Iron–Zinc Alloy By-Products in Hot-Dip Galvanizing. R. Haarmann. (*Metalloberfläche*, 1950, **4**, Aug., A113–A119). Hard iron–zinc alloys depositing on the bath walls in hot-dip galvanizing, which eventually break off and float to the surface, are responsible for losses of material and cause additional servicing. An examination of the structures of these by-products was made, and micrographs are shown. The question of combating their formation is discussed, and the possibilities of selling these by-products are considered—P. F.

Effect of Aluminium As an Alloying Element in Zinc Baths on the Quality of Hot-Galvanized High-Carbon Steel Wires. H. Gallbach and A. Pomp. (*Stahl u. Eisen*, 1951, **71**, Aug. 2, 805–817). The tabulated and plotted results of extensive tests show that the resistance to bending and fatigue strength of 0·77 and 0·67% C steel wires are considerably reduced by coating with Zn + 0·13% Al, as compared with coating with 99·995% pure Zn. The tensile strength is not affected to the same degree. The coating of steel wires with zinc containing aluminium additions should, therefore, be discontinued. (37 references).—A. G.

Liquid Chemical Blanket for Hot Galvanizing Surfaces. A. A. Paterson. (*Wire and Wire Products*, 1951, **26**, Oct., 918–919, 989). Field runs indicating 20–50% saving of raw spelter per ton of wire run are reported following the use of a chemical liquid blanket on hot-galvanizing pans. The chemical is manufactured by Dewey and Almey Chemical Co., Chicago.

Sherardizing: Modern Developments and Applications. A. E. Williams. (*Iron Steel*, 1951, **24**, Dec., 529–533). The author describes recent developments in the Sherardizing process for protecting iron and steel with zinc.—G. F.

The Theory and Practice of Hot-Dip Tinning. W. E. Hoare. (*Wire Ind.*, 1951, **18**, Oct., 867–875). Hot-dip tinning as applied to wire processing is described. The author deals with the theory of the process and proceeds with a detailed account by reference to a flow sheet. The tinning of both steel and copper wire is considered and electrotinning is also mentioned.—J. G. W.

Fundamentals of Tinning Practice. J. Teindl. (*Hutnik*, (Prague), 1951, **1**, No. 2, 37–39). [In Czech]. Methods of tinning sheet iron, faults arising during and before rolling of the sheet, and in preparing and tinning it are discussed, and some remedies considered. The qualities, dimensions, and uses of tinplate are mentioned.—P. F.

Etched Pattern Identifies Lighter Tinplate Coat. J. Kolb. (*Iron Age*, 1951, **168**, Aug. 2, 90–91). Positive identification of the more lightly coated side of dual tinplate is made possible by an etched diamond pattern. This lightly etched marking is applied at high speeds by a rubber roller using an acidified palm oil.—A. M. F.

Tallow Can Replace Palm Oil in Hot Dip Tinning. G. C. Ference and W. R. Johnson. (*Iron Age*, 1951, **168**, Aug. 2, 86–89). Practical tests indicate that modified prime beef tallow can be used as a substitute for palm oil in hot-dip tinning. The tallow is free from water and is high enough in flashpoint to permit straight additions. In the U.S.A. the cost is lower.—A. M. F.

Technology of Anti-Corrosive Coatings with a Phenolic Plastic Base. F. Garcia Estartus. (*Maquinas e Metais*, 1951, Sept., 17–20, 26). [In Spanish]. The chemical and physical properties of phenolic resins are reviewed.—R. S.

Continuous Dip System Improves Tar Coating. F. R. Adams and G. E. Loftin. (*Iron Age*, 1951, **168**, Aug. 2, 92–94). A continuous dipping system using a heated tar bath for cast-iron soil pipes and fittings is described. It is said to give a finish superior to that produced when pipes are heated and then dipped. Products cannot be overheated, and just enough residual heat for quick drying is retained.—A. M. F.

Cladding Steel Plates with Non-Ferrous Metals. K. Kurski. (*Hutnik*, (Warsaw), 1951, **18**, Oct., 409–413). [In Polish]. Methods of producing and welding clad steel plates are discussed and some examples of their application are given. V.G.

Waxes Now Used to Process as Well as Protect Materials. K. Rose. (*Mat. Methods*, 1951, **34**, Oct., 104–107). The properties and available forms of animal, vegetable, mineral, and synthetic waxes are briefly reviewed. Various recent applications are outlined.—P. M. C.

The Basic Types of Phosphate Coatings and Where to Use Them. R. F. Ayres. (*Mat. Methods*, 1951, **34**, Oct., 100–103). Iron, manganese–iron, zinc–iron, zinc, and aluminium-chromic phosphates are the five main generic types applied for the protection of iron, steel, zinc, cadmium, and aluminium. The properties, main uses, and methods of application are discussed.—P. M. C.

Testing Organic Finishes. (*Steel*, 1951, **129**, Nov. 26, 86–92). Methods of testing organic finishes including salt-spray tests, moisture resistance tests and weathering machines are described. An instrument for measuring the loss of reflectance of coated surfaces can be used for estimating weathering.

The measurement of colour retention, hardness, adhesion, and scratch resistance is discussed.—A. M. F.

Surface Preparation for Metallizing Shafts and Similar Objects. P. D. Dennison. (*Welding J.*, 1951, **30**, Sept., 835–836). The Dennison method of surface preparation is described. The surface is threaded to hold particles of molten sprayed metal. The threads vary from 20 threads/in. with 30° tool angle to 16 threads/in. with 60° tool angle, depending on the hardness of the base metal. After cutting, the tops of the threads are knurled to a depth of about 0·015 in. No other treatment is necessary.—U. E.

Broader Use of Hot-Sprayed Lacquer Seen on Military Equipment. (*Steel*, 1951, **129**, Nov. 12, 76–79). The advantages of hot spraying are described and brief descriptions of eight types of gun for spraying hot lacquer are given.—A. M. F.

Hot Spraying of Lacquer. J. A. Bede. (*Plating*, 1951, **38**, May, 461–463, 470). In the process evolved, specially developed lacquers are continuously circulated by a positive displacement pump through a coil heater to a spray gun, the unused lacquer being returned to the pump inlet. It is claimed that 50% less solvents are required than in cold-spraying owing to the lower lacquer viscosity at the operating temperature of 160° F., overspray losses are reduced, resulting in a 20% saving in lacquer, and less labour is required.—A. G.

Catalytic Combustion in Wire Enameling. R. J. Ruff. (*Wire and Wire Products*, 1951, **26**, 936–939, 987–988). Plant for the catalytic combustion of organic fumes generated during the enamelling of wire is described, performance characteristics are stated.—J. G. W.

Process Control in Making Enameled Wire. R. F. Thompson. (*Wire and Wire Products*, 1951, **26**, Oct., 885–887, 997–998). The dip and die processes for enamel coating of magnet wire are compared, and the author describes an automatic controller of viscosity and temperature of the resin solution used in the dip process. This controller was developed by Westinghouse Electric Corp.—J. G. W.

The Technology of Porcelain Enameling on Steel. E. E. Marbaker. (*Mech. Eng.*, 1951, **73**, May, 386–392). A brief survey of the history of enamelling is given followed by a discussion on the composition of enamels. Details are given of the manufacturing of enamel frits and the preparation of slips.—D. H.

Studies on the Imperviousness of Acid-Resistant Enamels. K. Frick. (Metalloberfläche, 1950, A, **4**, July, A98–A101). When cast iron is enamelled by sintering, the bottom layer of enamel is porous; this may lead to penetration by gases or liquids if the surface of the enamel is damaged. This is not the case when the enamel is fused on, as is always done on steel and occasionally on cast iron.—O. H. G.

POWDER METALLURGY

Infiltration Metallurgy. C. G. Goetzel. (*Research*, 1951, **4**, Dec., 555–561). A review is made of the principles and techniques of infiltration metallurgy, which is described as a method of achieving high-density powder-metallurgical compacts by filling the pores with a fluid, lower-melting-point metal. Some examples of applications are given.—C. J. B. F.

Steel Parts by Hot Coining. J. P. Scanlan. (*Powder Met. Bull.*, 1951, **6**, Dec., 78–80). The procedure of hot-coining a preformed compact, previously heated in a high-frequency furnace, has been used to produce high-density parts from three alloy steels. Careful selection of tools is essential. The method is economical in equipment and labour.—K. E. J.

Some Observations on the Role of the Binder in Cemented Refractory Alloys. J. T. Norton. (*Powder Met. Bull.*, 1951, 6, Dec., 75–78). The binder material not only cements together the hard particles, but influences the final strength. Recent experimental work on cemented tungsten carbide indicates that the hitherto accepted continuous 'carbide skeleton' does not exist, and that the carbide exists as isolated grains. The high transverse rupture strength of the heterogeneous sintered material (> 300,000 lb./sq. in., compared with approx. 100,000 lb./sq. in. for pure tungsten carbide) is attributed to the thin restrained films of the binder, in which plastic flow is prevented. Six important criteria for satisfactory binders are deduced.—K. E. J.

Production of Sintered Carbides. F. Šindler. (*Hutnik*, (Prague), 1951, **1**, No. 6, 130–131). [In Czech]. The composition of sintered carbides, details of the reduction processes applied to cobalt, tungsten, and titanium oxides as well as carburizing conditions are given. Melting points and densities of carbides are tabulated, and the latter are given as a function of sintering temperature, pressure, and location within the specimen.—P. F.

The Development of Cemented Carbides in Germany. E. Amman and J. Hinnüber. (*Stahl u. Eisen*, 1951, **71**, Oct. 11, 1081–1090: *Iron Steel Inst. Translation Series No.* 440, 1952). The development of tungsten carbide alloys, their microstructure, properties, and applications, and the increased use of tungsten-carbide/cobalt alloys containing titanium carbide are discussed. The addition of tantalum carbide to obtain greater hot hardness and resistance to crumbling during intermittent cutting is dealt with. [A translation is in course of preparation].—R. A. R.

Changes in the Technique of Manufacturing Cemented Carbides. C. Ballhausen. (*Stahl u. Eisen*, 1951, **71**, Oct. 11, 1090–1097). The author describes developments, particularly of electric furnaces, in the procedures for making hard metal alloys. The carbon tube furnace is of special significance. Reduction of the tungsten-bearing raw material, carburizing, mixing, crushing, grinding, screening, drying, pressing, and sintering, are all described with 50 diagrams.—R. A. R.

Economic Effects of Cemented Carbide Alloys on the Processes of Machining and Plastic Deformation. J. Holzberger. (*Stahl u. Eisen*, 1951, **71**, Oct. 11, 1098–1102). The economic advantages of using cemented carbide tools for machining and deformation processes are discussed and data are presented comparing cutting efficiencies and speeds, consumptions of tungsten, and numbers of regrinds for a high-speed steel (E Co 3) and a sintered carbide tool.—R. A. R.

The Effect of Type of Powder and Pressing Conditions on the Properties of Sintered Iron Parts. E. Bensch. (*Stahl u. Eisen*, 1951, **71**, Oct. 11, 1103–1114). Because higher tensile strength and elongation can be attained by sintering fine powders, grain sizes under 0·15 mm. are being increasingly employed. Fine powders are necessary in the production of sintered steel to improve diffusion conditions. The following properties are required in a powder for preparing moulded articles: Maximum freedom from oxygen; high chemical purity; good compactibility under low pressure; a surface condition and grain shape favouring high activity in the solid state; small shrinkage on sintering; and a good edge strength in the pressings. Densities up to 7·0 g./c.c., tensile strengths up to 20 kg./sq. mm. and elongations up to 10% are obtainable with the single-press method. This method is limited by the rigidity and abrasion resistance of pressing tools. Tensile strengths and hardnesses comparable with those of ingot iron of similar composition can be obtained by double or multiple-press methods.—J. P.

High Permeability "Sendust" Powder Ring Cores. E. G. Thurlby. (*Metal Progress*, 1951, **60**, Oct., 83–87). Sendust is an iron-rich Fe–Si–Al alloy. The author discusses experimental work to investigate its properties. He maintains that cores made under suitable conditions, as they are known at present, would form an acceptable substitute for Permalloy cores of 80 to 90 permeability.—J. P. S.

Powder-Metal Gears. D. W. Lynch. T. J. Snodgrass and T. T. Woodson. (*Machinist*, 1951, **95**, Oct. 6, 1506–1512). Applications, relative costs, tolerances, and manufacture are dealt with. The limitations of the process with regard to dimensional errors, and quality control are discussed.—E. C. S.

Powder Metal Gears Offer Economy Plus New Design Opportunities. C. G. Levin. (*Machine Design*, 1951, **23**, Aug., 117–119). Powder metal gears can produce cost savings of 67%. Photographs of gears which can be made from ferrous and non-ferrous alloys are shown. Their tensile strengths exceed 25,000 lb./sq. in.—E. C. S.

Heat-Resisting Materials Fabricated by Powder Metallurgy. W. D. Jones. (*Met. Ital.*, 1951, **43**, Oct., 425–431). The author classifies materials used in the manufacture of heat-resisting machine parts into: (1) Refractory oxides; (2) coal in its various forms; and (3) platinum. He briefly indicates their characteristics. Powder-metallurgy methods produce very good heat-resisting materials. (10 references).—M. D. J. B.

PROPERTIES AND TESTS

British Standard Mechanical Tests for Metals. (*BS Handbook No.* 13, 1951). This 243-page handbook brings together all methods of mechanical testing established in British Standards.—R. A. R.

Alternating Torsion Testing of Wires. R. Zoja. (*Met. Ital.*, 1951, **43**, Oct., 421–424). In alternating torsion tests on wires, three stages may be identified : (1) Uniform deformation over the full length of the specimen ; (2) local deformation ; and (3) failure of the specimen with a more or less fibrous fracture. Results obtained with steel, copper, nickel, aluminium, and alloy wires suggest that the method is technically sound.—M. D. J. B.

Upper and Lower Transitions in Charpy Test. W. J. Harris, jun., J. A. Rinebolt, and R. Raring. (*Welding J.*, 1951, **30**, Sept., 417s–422s). Charpy **V**-notch specimens of medium-carbon steels were impact-tested with multiple low-velocity, low-energy blows. A discontinuity in the energy–temperature relationship, at temperatures below which the fracture surface was nearly all crystalline, was observed. This discontinuity was associated with the occurrence of plastic-strain markings on the sides and top of the specimens.—U. E.

The Effect of Fabrication Processes on Steels Used in Pressure Vessels. S. S. Tör, J. M. Ruzek, and R. D. Stout. (*Welding J.*, 1951, **30**, Sept., 446s–450s). The effect of sizing of plates by machining, flame-cutting, or shearing on notch toughness of the steel was investigated. Flame-cutting and shearing lower the notch toughness. The transition temperature is raised by post-heating at 500° F. and a post-heat at 1150° F. was beneficial, but post-heating at 1600° F. lowered the transition temperature below — 160° F. This shows that adverse effects of flame-cutting or shearing are not due to formation of notches at the surface but to metallurgical changes.—U. E.

Further Tests on Effects of Plastic Strain and Heat Treatment. S. S. Tör, R. D. Stout, and B. G. Johnston. (*Welding J.*, 1951, **30**, Nov., 576s–584s). Investigations on the effect on transition temperature of pressure-vessel steels of 20% tensile strain, cylindrical bending, and after hot or cold spherical pressing are reported. It was found that a tensile strain of 20% in the direction of rolling raised the ductility transition temperature of the steels approximately 80° F. Steels strained 20% transverse to the rolling direction had transition temperatures 130° F. higher. Tests on spherically hot- and cold-pressed specimens indicate that cold pressing raises the transition temperature whereas hot pressing results in transition temperatures that are equal to or better than those of the unpressed steels.—U. E.

Effect of Strain Hardening and Tempering on 18/8 Stainless Steels. P. Bastien, J. Dedieu, and A. Portevin. (*Metal Treatment and Drop Forg.*, 1951, **18**, Oct., 564–468). A metallographic technique of using a fine suspension of the magnetic oxide of iron, to differentiate between α-phase and austenite in 18/8 stainless steels, is described. The results demonstrate : (*a*) the possibility of producing, by cold-working, considerable γ–α transformations at ordinary temperatures, which are not, or only partly, obtainable by cooling below the ambient temperature ; and (*b*) the possibility of formation of a sigma phase by tempering a low-carbon 18/8 steel after cold-working.—P. M. C.

Deformation of Mild Steel in the Blue-Brittle Range. E. O. Hall. (*J. Iron Steel Inst.*, 1952, **170**, Apr., 331–336). [This issue].

Elements of the Internal Mechanics of Metals. P. Coron. (*Bull. Cercle Etudes Mét.*, 1950, **5**, Mar., 285–312 ; June, 313–333). This theoretical discussion deals with the rupture and deformation of metal in terms of a new concept, the 'constraint vector,' which represents the force acting across any unit surface in the material. The summation of these forces at any point determines the deformation, the forces being greatly influenced by heterogeneities within distances of the order of magnitude of the unit surfaces.—E. T. L.

The Scattered Light Method of Exploration of Stresses in Two- and Three-Dimensional Models. H. T. Jessop. (*Brit. J. Appl. Phys.*, 1950, **2**, Sept., 249–260). It is shown theoretically that scattered light observations provide in many cases the quickest and the most accurate means of measuring principal stress differences in a three-dimensional model, and also of separating the stresses in a two-dimensional problem. A method is developed by which a high intensity may be obtained in the light scattered from a very narrow beam traversing the model, and this, combined with an improved measuring technique, permits a relatively high degree of accuracy in the observations.—J. A. L.

Photoelastic Determination of Free Boundary Stresses on "Frozen Stress" Models by an Oblique Incidence Method. V. M. Hickson. (*Brit. J. Appl. Phys.*, 1951, **2**, Sept., 261–269). The methods of determining the stress at the boundary of a three-dimensional photoelastic model are reviewed and the oblique incidence method as applied to boundary points is investigated in detail.—J. A. L.

Three-Dimensional Photoelasticity. R. C. O'Rourke. (*J. Appl. Phys.*, 1951, **22**, July, 872–878). The classical Sommerfeld-Runge method for deriving the laws of geometric optics in isotropic inhomogeneous media from Maxwell's equations is applied to problems in weakly anisotropic and inhomogeneous media.—J. P. S.

The Micro-Mechanism of Fracture in the Tension Impact Test. Supplementary Report No. 1. W. H. Bruckner. (*Welding J.*, 1951, **30**, Sept., 459s–468s). Tension impact tests were made on a rimmed and killed structural steel in which spheroidizing had eliminated all evidence of lamellar carbide structure. Tests were made on Armco iron for comparison. The initial step in the fracture of the spheroidized steels was noted from partial fracture tests to be the microfracture of the spheroidal carbides at the ferrite grain boundaries. The general absence of twinning in the ferrite was ascribed to the stress-relief mechanism afforded at grain boundaries through the cracking of carbide spheroids. The formation of mechanical twins in regions of low stress at the outer edges of the notch volume was the prominant feature.—U. E.

The Internal Friction of Metals, Its Measurement and Its Application to the Problems of Physical Metallurgy. B. Edmondson. (*J. B'ham Met. Soc.*, 1951, **31**, June, 75–104). This is a non-mathematical review.—J. B. B.

Production Problems—X : Surface Cracks in Cams. (*Iron Steel*, 1951, **24**, Nov., 509–510, 514). This article describes an investigation into the causes of surface cracks on ground cams. Blame could be apportioned between grinding pressure and the presence of small isolated regions of brittle carbide films, resulting from unsatisfactory heat-treatment.—G. F.

Production Problems—XI : Failure of Special Tension Bolts. (*Iron Steel*, 1951, **24**, Dec., 541–542). A brief description is given of an examination of special tension bolts which had failed in the heads when tightened up. Failure was probably due to the condition of the material in the heads, which showed excessive cold work.—G. F.

Concerning Effects of Size on the Yield and Fatigue Strengths in Bending. A. Schaal. (*Z. Metallkunde*, 1951, **42**, Sept., 279–284). Surface stress measurements, without a calibrating standard, were carried out by X-rays on rectangular specimens of Cr–Mn steel and a light alloy, the specimens varying in area of cross section. In annealed specimens a considerable decrease in stress was observed in tensile stressing on yielding, while in bending the yielding of the surface layer induces only a comparatively small decrease in the stress in that layer, the decrease becoming pronounced only on further deformation. The X-ray measurements thus indicate a higher yield strength in bending than in tension. The magnitude of the effect increased with decreasing area of section, *i.e.*, with increasing stress gradients. With still higher stress gradients no further increase was found. These phenomena, as well as the differences in the flow of the surface crystallites are explained by the tendency of the crystals below the surface, in bent specimens, to counteract the flow stress because they are still elastic.—P. F.

Internal Strains. Their Influence on Hardness. P. Blain. (*Etudes, Document. Mét.*, 1951, Apr.–May–June, Bull., 67–74). Several simple cases of internal strain in steel are reviewed. These include strains resulting from rapid cooling, from deformation in the cold, and cold drawing. The influence of residual strain, existing on the surface, on hardness is discussed. Rockwell hardness was determined on both sides of discs which had been deformed using a special apparatus, which is described. The convex surface of a deformed disc is under tension and the concave surface under compression. The results indicate that the superficial hardness of a hard steel varies in the ratio of 1 to 5 when the metal is subjected to internal strains of extension or compression of the order of 165 kg./sq. mm.—T. E. D.

The Technique of Hardness Measurement. J. M. Bonomi. (*Rev. Gén. Méc.*, 1951, **35**, June, 181–187). Hardness in austenitic steels, light alloys, and cold-rolled sheets is discussed. The principles of the Brinell, Vickers, and Rockwell tests are described and compared. The relationships between hardness and tensile strength are considered.—R. S.

A Theory of Rockwell Ball Hardness. M. A. du Toit Meyer.

(*Appl. Sci. Res.*, 1951, **A 3**, 1, 11–26). A theoretical analysis of the Rockwell method of ball hardness measurements is made. A general expression for Rockwell hardness numbers in terms of the Meyer constants n and b is given, and the conversion of Meyer and Brinell hardness numbers to Rockwell hardness numbers is discussed. The theoretical treatment agrees with experimental results.—T. E. D.

The Theoretical Basis of the "Emcotest" Hardness Tester. L. Tschirf. (*Betrieb u. Fertigung*, 1951, **5**, May, 80–83; June, 94–96; Aug., 129–133). The Emcotest hardness tester normally makes tests of the Rockwell type, but can be used for other types of test if a separate microscope is employed for measuring the impression. Its design and tests of its accuracy are described, with particular reference to the spring loading device, the measurement of depth of impression, and permissible errors.—H. R. M.

Hardness and Wear. W. Späth. (*Metalloberfläche*, 1950, A, **4**, Dec., A177–A180). It is shown that the relation between hardness and wear is rationally and most usefully represented by plotting wear against the inverse of the hardness. The relation of hardness to wear is similar to that of the tensile strength to the fatigue limit. A wear limit is defined as that frictional load which will just not lead to progressive wear by a sequence of work-hardening, embrittlement, and disintegration of the embrittled surface layer. In a few practical examples given, the relation between wear and the inverse of the Brinell or Vickers hardness is shown. Examples of the relation between wear and tensile strengths of lead- and air-patented wires are also given. Wear-testing equipment designed by the author is described.—P. F.

A Correlation of End-Quenched Test Bars and Rounds in Terms of Hardness and Cooling Characteristics. E. W. Weinman, R. F. Thomson, and A. L. Boegehold. (*Amer. Soc. Met. Preprint* 31, 1951). The authors obtain a more precise connection between the results of Jominy tests, and the hardness of as-quenched rounds. The results are presented in correlation charts, which cannot, however, be very accurate.

Limitations of the End-Quench Hardenability Test. A. R. Troiano and L. J. Klinger. (*Amer. Soc. Met. Preprint* 30, 1951). It was found that relative hardenabilities derived from standard end-quench tests are not valid with smaller specimens. This means that the test is of limited value in evaluating performance in practice.—E. T. L.

A Study of the Microhardness of the Major Carbides in Some High-Speed Steels. P. Leckie-Ewing. (*Amer. Soc. Met. Preprint* 36, 1951). About a third of the carbides in high-vanadium steels are extremely hard, but in standard high-speed steels the major carbide is a complex tungsten–molybdenum-rich carbide, not quite so hard.—E. T. L.

The Influence of Experimental Conditions in End-Quench Tests on Steel. W. Peter and A. Rose. (*Arch. Eisenhüttenw.*, 1951, **22**, Sept.–Oct., 303–312). The method of quenching, the dimensions of the specimen, and the heat-treatment before quenching were varied in experiments designed to establish reproducibility of results in Jominy end-quench tests. In the case of certain chromium and chromium–vanadium steels, good reproducibility was found whether German, American, or British standards were adopted—all leading to closely similar results. Rockwell hardness fluctuations for different specimens of the same steel, taken at similar distances from the quenched end, were found not to exceed $\pm$ 1·5 hardness numbers, which lies within the limit of experimental error. Test pieces about 4 in. long were found best, but 3-in. specimens were also suitable.—P. F.

The Deformation and Ageing of Mild Steel. Part I. W. Sylwestrowicz and E. O. Hall. (*Proc. Phys. Soc., B.*, 1951, **64**, June, 495–502). Mild steel deforms by a series of bands of plastic deformation called Lüders bands. In heavy tensile specimens a complex series of bands may arise, but in thin wire specimens it is shown that only single bands are formed. Measurements have been made of the propagation stress and Lüders strain for these single bands, and the effects which occur on ageing deformed specimens have been studied. A critical examination of current theories of the upper yield point—the stress at which bands first appear—is also undertaken.—R. A. R.

A Basic Guide for Management's Choice of Non-Destructive Tests. R. C. McMaster and S. A. Wenk. (Symposium on the Rôle of Non-Destructive Testing in the Economics of Production: *Amer. Soc, Test. Mat. Special Tech. Pub. No.* 112, 1951, 3–80). In this extensive review the nature and critical features of non-destructive tests are discussed with reference to existing commercial instruments, and the principle of operation of each test method is briefly stated. A classified list of 250 patents and 500 technical articles is given.—J. B. B.

Discontinuities in Cast and Wrought Products That Can Be Revealed by Non-Destructive Tests. K. R. Van Horn. (Symposium on the Rôle of Non-Destructive Testing in the Economics of Production: *Amer. Soc. Test. Mat. Special Tech. Pub. No.* 112, 1951, 83–100). The ASTM Tentative Industrial Radiographic Terminology for the Radiographic Inspection of Castings and Weldments (E 52–49T), is illustrated by prints representing typical discontinuities for each subdivision. The sensitivity limitations and important applications are briefly described for radiographic, fluorescent penetrant, magnetic particle, and ultrasonic methods of testing.—J. B. B.

The Rôle of Non-Destructive Testing in the Economics of Castings. J. W. Juppenlatz. (Symposium on the Rôle of Non-Destructive Testing in the Economics of Production: *Amer. Soc. Test. Mat. Special Tech. Pub. No.* 112, 1951, 102–108). The more common methods of non-destructive testing are discussed with reference to their effects on foundry operations, final mechanical processing, and ultimate costs of casting products.—J. B. B.

The Economics and Practical Application of Cobalt 60 in the Radiographic Inspection of Steel Weldments. W. L. Schwinn. (Symposium on the Rôle of Non-Destructive Testing in the Economics of Production: *Amer. Soc. Test. Mat. Special Tech. Pub. No.* 112, 1951, 112–129). The industrial application of cobalt^{60} in the inspection of steel weldments is investigated. Radiographs which have been exposed with variable X-ray voltages in the range 250 to 2000 kV. are studied and compared with similar exposures with gamma rays from radium and cobalt,^{60} on plates 1 to 4 in. thick. The economic aspect, exposure times, and sensitivity charts covering these results are presented. Results indicate that only where fine radiographic detail is required is cobalt^{60} superior to radium.—J. B. B.

The Economics of Wrought Steel Inspection. C. D. Moriarty. (Symposium on the Rôle of Non-Destructive Testing in the Economics of Production: *Amer. Soc. Test. Mat. Special Tech. Pub. No.* 112, 1951, 136–144). The economic value of non-destructive testing to the wrought steel user is discussed. The rôle this type of testing has in the user's manufacturing cycle, and the part ultrasonics and the testing of material in motion have in the saving of man-hours are considered.

Heat Conduction in Simple Metals. M. L. Storm. (*J. Appl. Phys.*, 1951, **22**, July, 940–951). It is shown that a mathematical condition for the transformation to linear form of the one-dimensional, non-linear, partial differential equation of heat conduction is the constancy of $[1/(KS)^{\frac{1}{2}}](d/dt)\log(SK)^{\frac{1}{2}}$: where K is the thermal conductivity and S the product of density and specific heat at constant pressure. Applications of the transformed equation to the solution of problems in heat conduction are considered.—J. P. S.

Heat Conductivity of Steels and a Few Other Metals at Low Temperatures. J. de Nobel. (*Physica*, 1951, **17**, May, 551–561). Thermal conductivities of aluminium, iron, nickel, Monel metal, and of nickel-, manganese-, and chromium steels were investigated at the temperatures of liquid hydrogen and liquid air. Details are given of the two experimental methods used, and data about the chemical analysis, heat-treatment, and Brinell hardness of the samples are included. Results are given in tabular and graphical form.—T. E. D.

A Recording Dilatometer for High Temperatures. W. R. Apblett and W. S. Pellini. (*Amer. Soc. Met. Preprint* 2w, 1952). A dilatometer with which a small electrically heated rod-like specimen is used is described. Dilatation is measured by strain gauges mounted on a spring bent by the specimen changing in length. The speed of response is high.—E. T. L.

Statement on the Occurrence of Graphitization in Carbon Steel of Stainless-Clad Vessels. (*Welding J.*, 1951, **30**, Nov., 544s–545s). Graphitization in carbon steel of stainless-clad vessels is discussed and future researches are outlined.—U. E.

Hot-Workability of Stainless Steel Improved by Adding Cerium and Lanthanum. C. B. Post, D. G. Schoffstall, and H. O. Beaver. (*J. Met.*, 1951, **3**, Nov., 973–977B). The effects of additions of cerium and lanthanum to stainless steels on the hot-workability were evaluated using cone-shaped specimens. These elements improve the hot-workability of steels containing 4–70% Ni and 10–60% Cr + Mo + W, the

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amount of any one element in the latter group not exceeding 30%. The nickel content chiefly determines the minimum and maximum additions required. The improvement in hot-workability in typical cases is described and illustrated.—G. F.

Overheating of Steel : Review of Present-Day Knowledge. (*Iron Coal Trades Rev.*, 1951, **163**, Oct. 26, 903–909). This article reviews present-day knowledge of the phenomenon of overheating of steel. The problem has two parts : (1) The understanding and control of the process, and (2), the recognition of the symptoms. The mechanism of overheating and its causes and effects are considered and methods of detecting overheating and preventing its occurrence are discussed. The results of several recent researches on the subject are reviewed.—G. F.

Effect of High Heating Rate on Some Elevated Temperature Tensile Properties of Metals. W. K. Smith, C. C. Woolsey, jun., and W. O. Wetmore. (*Amer. Soc. Met. Preprint* 27, 1951). Specimens were subjected to constant load and heated rapidly until rupture occurred. Strength data for various steels indicate that design stresses higher than those based on short-time high-temperature tests can be safely withstood when the stress occurs only briefly during heating.—E. T. L.

Three Lines for Development of Heat-Resisting Alloys. L. Colombier. (*Métaux-Corrosion-Indust.*, 1951, **26**, May, 218–223). The three ways for preventing formation or development of lines of slip are : (1) The presence of precipitated substances such as oxides, carbides, or intermetallic compounds ; (2) cold or hot working ; and (3) casting. Titanium and other steels are cited as examples.—N. MCE.

Research Pushed on Gas Turbine Blade Materials. A. H. Allen. (*Steel*, 1951, **129**, Aug. 27, 72–75, 101). This article describes the work of metallurgists from industry, universities, and the Lewis Flight Propulsion Laboratory of the National Advisory Committee for Aeronautics on cast and forged alloys, sintered metal powders, and ceramic materials to find replacements for niobium, tungsten, cobalt, nickel, chromium, and molybdenum, and to perfect blades having longer life at high operating temperatures.—M. D. J. B.

Thermal Stability of Cast Iron and the Influence Thereon of Various Alloying Elements. H. Timmerbeil, G. Clas, and O. Mattern. (*Giesserei*, 1951, **38**, Oct. 4, 523–526). Investigations by the Verein Deutscher Giessereifachleute on the stability of castings are reported, in which the influence of phosphorus on the scaling resistance of cast iron and the behaviour of silicon, chromium–silicon, and aluminium–silicon alloy cast iron were studied. Reference is made to a patent application, which arose from the investigations, for a non-scaling cast iron containing 1·85% C, 6% Si, 0·6% Mn, 0·6% P, <0·025% S, 4% Al and 0·2% Ti.—J. G. W.

High-Temperature Properties and Characteristics of a Ferritic Steam-Piping Steel. A. W. Rankin and W. A. Reich. (*Trans. Amer. Soc. Mech. Eng.*, 1951, **73**, Oct., 891–904). The authors review the high-temperature properties, and manufacturing and heat-treating characteristics of a Cr–Mo–V steel. The General Electric Company, U.S.A., utilizes it for turbine shells, valve casings, and steam pipes in service at 1050° F. Corresponding properties and operating experiences are also presented on the chromium-free Mo–V steel previously used.—D. H.

Development of Research in High-Temperature Rheology of Metals. P. Feltham. (*Metal Treatment and Drop Forg.*, 1951, **18**, Sept., 389–394 ; Oct., 455–459). A critical examination of trends and methods in the development of rheology of metals, is followed by a brief review of modern ideas on equations of state and anelasticity at high temperatures. New methods which are slowly coming into prominence are described. (45 references).—P. M. C.

Metals for Gas Turbines (Land and Marine). J. M. Robertson. (*J. B'ham Met. Soc.*, 1951, **31**, Sept., 122–148). Factors involved in the use of metals in gas turbines are reviewed with reference to their service, the production of components, operating conditions, and the relation of materials to components. A list is given of materials available and being used or considered by C. A. Parsons and Co., Ltd., in the construction of gas turbines.—J. B. B.

Relation between Internal Friction and Creep Strength of a Steel as a Function of Microstructure. C. Boulanger, G. Delbart, and M. Ravery. (*Comptes Rendus*, 1951, **233**, Oct. 8, 794–796). Measurements of internal friction, taking into account the viscosity of grain boundaries, on four micrographic structures of a single steel enable a classification to be made, identical with that obtained by creep tests. Further evidence is obtained of the favourable influence on high-temperature strength of a large grain size and a bainitic structure.—A. G.

New Cerium-Bearing Alloy Steels Offer Greater Hot Ductility. (*Steel*, 1951, **128**, June 4, 98). The effects of adding cerium to certain scarce high-alloy, heat and corrosion resistant materials are discussed. It is found that adding cerium results in alloys which can be readily hot-worked with fewer cracks and tears and with better finishes. The work of the research laboratories of Carpenter Steel Co., Reading, Pa., is reviewed. Tests show possibilities of increasing mill yields from ingot to hot-rolled bars, plates, tubes, and forgings in high-alloy steels. These discoveries are now patented.—M. D. J. B.

Comparison of the Influence of Additions of Titanium, Niobium, and Tantalum on the Properties of Steels. A. Kohn. (*Rev. Mét.*, 1951, **48**, Sept., 687–709). Binary alloys of these three elements with iron, and ternary alloys with iron and carbon are studied. The elements give very stable compounds with carbon and nitrogen and have greater solubility in austenite than in ferrite. The influence of additions on such properties of steels as (*a*) intergranular corrosion, (*b*) creep resistance, (*c*) hot stability, (*d*) resistance to oxidation, (*e*) autoquenching, (*f*) the ageing of mild steels, and (*g*) nitriding is discussed. Niobium and titanium have in general a similar effect except that creep resistance is greater for niobium steels. Tantalum being similar chemically probably has a similar effect.—A. G.

The Employment of Nickel in the Manufacture of Special Steels. (*Aciers Fins Spéc. Franç.*, 1951, July, 27–29). The sources of nickel are listed. The influence of nickel on the $\gamma \rightarrow \alpha$ iron transformation is discussed and its uses in stainless, heat-resisting, magnetic steels are described. The principal steels contain 0·08% and 1·4 to 6% Ni; 0·1–1% Mo is often added, generally 0·6–2% Cr, and sometimes, for certain machine tools, a little vanadium or tungsten.—E. C. S.

Titanium and Zirconium—Emergency Substitutes for Manganese. W. W. Austin, jun. (*Steel*, 1951, **129**, Nov. 5, 110–115). The hot bend impact test has been used as a criterion of hot shortness in determining the Mn/S ratio required to prevent this. Zirconium may be used to replace the manganese in steels with sulphur between 0·025 and 0·96%, and titanium in steels with sulphur contents between 0·02 and 0·05%. Titanium retention was found to be far superior to zirconium retention.—A. M. F.

The Influence of Hydrogen on the Elasticity and the Inelasticity of Iron and Steel. P. Bastien and P. Azou. (*Génie Civil*, 1950, **127**, Sept. 1, 333–334). It is concluded that the influence of hydrogen, introduced by electrolysis or acid attack, on the elastic and inelastic properties of iron and steel is feeble compared with the influence of this gas on the plastic deformation and rupture characteristics.—T. E. D.

A Typical Example of Embrittlement Due to Hydrogen at High Temperature and Pressure. R. Cardano and P. I. W. Colantoni. (*Calore*, 1951, **22**, Oct., 359–370). [In Italian]. This paper describes tests on an ammonia pressure vessel of 3% nickel steel after 13 years' service. Mechanical, micrographic, and chemical tests show that the steel has reached an advanced stage of hydrogen embrittlement. The authors conclude that the mechanical properties of the steel are considerably lowered after service at 350–400° C. and 750–800 atm. pressure. The steel shows marked decarburization but no desulphurization with no improvement after heat-treatment.—M. D. J. B.

Studies of Metallurgical Reactions. I—The Thermal Dissociation of Sulphates of Iron, Zinc, and Lead. H. N. Terem and S. Akalan. (*Rev. Faculté des Sciences de l'Université d'Istanbul*, 1951, **16**, 3, 150–161). [In French].

Buying Steel Castings. (*B.S.F.A. Bulletin*, 1951, **2**, Dec.). In addition to general information on the manufacture of steel castings a table is presented entitled "Summary of Chemical Composition and Mechanical Test Requirements of British Standards for Steel Castings together with Designations of other equivalent British and American Specifications."

Stress Strain Relationship of a High Tensile Weldable Structural Steel. D. W. Smith, J. G. Whitman, and C. L. M. Cottrell. (*Ministry of Supply, Directorate of Weapons Research (Defence) W.R.D.*, 11/51, 1951, Oct.). An investigation into the relationship between stress and strain of a high-tensile weldable structural steel is described. The steel is a low-carbon, Mn–Mo steel, giving a minimum 0·3% proof stress of 28 tons/sq. in. for thicknesses of less than 0·5 in. in the

as-rolled condition. Its limit of proportionality is low, 12 tons/sq. in., prohibiting its application to the construction of prefabricated transportable bridges because of risk of distortion sufficient to endanger the interchangeability of parts.—T. E. D.

High-Tensile 'Als' Steels for Light Structures. A. Bartocci. (*Ossature Métallique*, 1951, **16**, Dec., 594–598). New low-alloy, low-carbon steels developed by the Terni Company for light structures are described in detail. The relation of mechanical properties to heat-treatment is shown in tables. Tensile strengths range from 50 to 65 tons/sq. in.—P. F.

Molybdenum and Boron Steels. N. Tisdale. (*Metal Treating*, 1951, **11**, July–Aug., 6, 7, 23). The usefulness and benefits of small boron additions to 'lean' alloy steels are briefly discussed. Molybdenum and other scarce alloys may be conserved, whilst strength and hardness are maintained at satisfactory levels.—P. M. C.

Molybdenum Can Replace Chromium in Bearing Steels. A. S. Jameson, A. D. Ellis, and G. F. Meyer. (*Iron Age*, 1951, **167**, Apr. 5, 102–107). Experiments have been carried out to investigate the possibilities of replacing 1·0 to 1·5% Cr with 0·5% Mo in the standard E-52100 steels used for ball-bearing race rings. Satisfactory results have been obtained and the heat-treating and annealing cycles have been worked out. Experimental heats of molybdenum–boron bearing steel also gave satisfactory test results.—A. M. F.

Recent Metals and Alloys. A. G. Quarrell. (Brit. Assoc.: *Engineering*, 1951, **172**, Sept. 14, 343–344; Sept. 21, 378–379). Alloys, with high strength/weight ratios, suitable for the aircraft industry are examined and the characteristics of several new non-ferrous alloys are discussed. Information is given on the demands made by the gas turbine and reference is made to ferritic and austenitic steels, the complex *G18B* alloy, and to copper alloys.—M. D. J. B.

The Iron Age Chart of Comparable Tool Steel Brands. (*Iron Age*, 1951, **167**, June 28, 70A). This chart gives a table of the trade names employed for tool steels by about 15 firms.—A.M.F.

Hard Facing Alloys, for Steel Mill Use. H. S. Avery. (*Iron Steel Eng.*, 1951, **28**, Sept., 81–106). The author discusses the properties of hard-facing alloys and the principal factors which govern wear. Amongst the alloys considered are the tungsten carbide composites; high-chromium irons; martensitic irons; cobalt-base alloys; nickel-base alloys; and martensitic, pearlitic, and austenitic steels and copper-base alloys. Wear is classified in three basic groups: thermal, chemical, and mechanical—M. D. J. B.

Nickel Shortage Shifts Focus to Type 430 Stainless. (*Steel*, 1951, **129**, Aug. 20, 66–68, 86–88). This article describes how the necessity of doing without the nickel-bearing stainless steels is driving manufacturers to investigate the possibilities of type 430 (17% chromium stainless steel) for utilization where 18/8 grades were employed formerly. The difficulty in working 430 stainless steel is discussed.—M. D. J. B.

What Do You Know About Stainless? H. E. Boyer. (*Steel Processing*, 1951, **37**, June, 287–292; July, 345–349). This is a descriptive article giving general information about the types, compositions, properties, and uses of stainless steels. The compositions of typical martensitic, ferritic, and austenitic types, and the properties and uses of the first-mentioned are discussed. The surface carburization of certain martensitic types and the properties and uses of ferritic, austenitic, and a few special qualities are dealt with.—P. M. C.

The Uses of Stainless Steel in Surgery. (*Acciaio Inossid.*, 1951, **18**, Sept.–Oct., 5–7). [In Italian]. Stainless steel in the fabrication of an artificial heart and lungs to be used in surgery is discussed and details of the extremely delicate apparatus are given.—M. D. J. B.

Use of Stainless Steels. H. Forder. (*Ossature Métallique*, 1951, **16**, Dec., 599–602). Uses and potentialities of stainless steels of the 18/8 and of the ferritic and martensitic chromium types are discussed. Applications in structures, cutlery, storage tanks, railway carriages, cars, television, and surgery are listed.—P. F.

Steel for High-Pressure Tubes. D. Cecchi. (*Ossature Métallique*, 1951, **16**, Dec., 580–582). The development of high-pressure tubing manufacture in Italy over the past 20 years is surveyed, and the most recent method of making tubes of welded, high-tensile low-alloy steels is described.—P. F.

New Technical Specifications for High Pressure Boiler Tubes. B. Počta. (*Hutnik*. (Prague), 1951, **1**, No. 2, 43–44). [In Czech]. New Czechoslovak standards relating to high-pressure tubing working at pressures up to 125 atm. and even higher, and at temperatures up to 600° C., are discussed.—P. F.

How to Save Alloying Elements in Structural Steels. (*Hutnik*. (Prague), 1951, **1**, No. 6, 126–127). [In Czech]. Tables giving the composition, tensile properties, and surface hardness of standard Czech low-alloy structural steels are given, and their special features are discussed. The steels were developed without the use of either nickel or molybdenum, and are of the Mn–Cr, Mn–Cr–V, Mn–Cr–Al–V and Mn–Si–Cr–V types.—P. F.

Tool Steels Developed for Varied Applications. C. B. Post. (*Steel*, 1951, **129**, Nov. 12, 84–89, 98). The available varieties of tool steel are discussed and classified under the jobs they are expected to carry out such as die steels, high-speed steels, and extrusion steels. Manufacturing techniques have led to the production of steels of high impact strength, high fatigue resistance, high hardness, and resistance to wear and abrasion, which can be heat-treated.—A. M. F.

Work and Tool Materials Have Definite Properties. M. C. Shaw and P. A. Smith. (*Machinist*, 1951, **95**, Oct. 27, 1631–1634). The authors discuss structures produced by quenching, properties of steels and irons, effects of alloying constituents, and properties of ferrous tool materials.—E. C. S.

Steel Products Manual, Section 20. Wrought Steel Wheels. (*Amer. Iron Steel Inst.*, Nov., 1951). This 104-page handbook gives information on tolerances, methods of inspection, definitions of terms, manufacturing practices, design data, and specifications for wrought steel wheels for rolling stock.

Mechanical and Technological Tests on Cast Iron. A. Vetiška. (*Hutnik*, (Prague), 1951, **1**, No. 6, 128–129). [In Czech]. Czechoslovak and foreign practice in works and laboratory testing of cast irons for graphitization, fluidity, machinability, tensile shear and bending strengths, impact, and damping are described and specimen dimensions are given.—P. F.

Nickel Cast Iron for Engineers. (*Australian Foundry Trade J.*, 1951, **2**, Aug., 3–5). This is a brief review of the properties and uses of cast irons containing various amounts of nickel.

French Standardization of Steel Products. (*Aciers Fins Spéc. Franç.*, 1951, July, 10–16). In the introduction, a brief history of attempts to rationalize the French manufacturing programme since 1879 is given. Steel product standards can be divided into four categories: (1) General terminology and definitions; (2) testing methods; (3) dimensional standards; and (4) product or technical specification standards. The author discusses these.—E. C. S.

Boron Steels a New Era in Alloy Metallurgy. D. I. Brown. (*Iron Age*, 1951, **168**, July 5, 79–85; July 12, 85–90; July 19, 102–106; July 26, 68–72; Aug. 9, 75–78). This series of articles gives the latest information about the boron steels developed by the Amer. Iron Steel Inst. and the Soc. Automotive Eng., and how they can replace alloy steels. Heat-treating, carburizing, and machining characteristics are discussed. Case histories of application in gears, axles, springs, and allied parts are presented in detail. Experiences of manufacturers who have the new steels in production and the hardenability information on these actual applications are cited.—A. M. F.

Occupational Diseases in Metal-Surface Work. K. H. Sroka. (*Metalloberfläche*, 1950, A, **4**, Dec., A187–A189). Hazards to health in work involving lead, zinc, nickel, mercury, chromium, arsenic, and antimony are discussed. The nature and symptoms of the poisoning are described, and the functions and adequacy of preventive and curative measures are examined.—P. F.

Metal Finishing Research. (*Product Finishing*, 1951, **4**, May, 85–87). The 31st Annual Report of the Brit. Non-Ferrous Metals Res. Assoc. is summarized. The process for applying lead coatings to steel and copper has aroused much interest and is being further developed. Work is in hand to determine the cause of rough nodules on the surface of bright nickel coatings. The adhesion of electrodeposits of zincate-dipped aluminium and magnesium appears to depend on the mode of growth of the zinc layer. Laboratory investigations have indicated that the amount of 'ash' found in hot galvanizing baths can be reduced by additions to the bath. Attempts are being made to determine the spreading power and useful life of flux covers designed to minimize metal losses in wet galvanizing. It has been shown that the effect of

aluminium in modifying the structure of hot-dipped zinc coatings depends on the proportions of other elements in the zinc.—J. P.

METALLOGRAPHY

Metallographic Techniques for Austenite Grain Size of Steels in the As-Cast State. E. A. Loria. (*Trans. Amer. Inst. Min. Met. Eng.*, 1951, 1029–1030; *J. Met.*, 1951, **3**, Nov.). The author briefly describes and illustrates the use of a modified nitro-sulphuric reagent as a grain-contrast reagent, and of a 6% nital 1% Zephiran-chloride reagent as a grain-boundary delineator, in the study of the grain size of as-cast austenitic steels in which the pro-eutectoid ferrite envelope is suppressed.—G. F.

Structure Rating Charts for Steel and Cast Iron. H.-J. Wiester and G. Finke. (*Stahl u. Eisen*, 1951, **71**, Sept. 13, 1002–1011). The literature on the development and present status of structure rating charts for steel and cast iron is discussed.—J. P.

Some X-Ray Diffraction and Electron Microscope Observations on Temper Brittleness. S. R. Maloof. (*Amer. Soc. Met., Preprint* 22, 1951). After embrittling treatment there is a decrease of the lattice parameter of ferrite, but no change in the composition of the carbide phase. The carbide particle sizes and distribution vary between the four low-alloy nickel–chromium steels that were studied.—E. T. L.

Band Structure Revealed by Metalloscope Examination. M. Ricolfi. (*Etudes Document. Mét.*, 1951, Apr.–May–June, Bull., 75–77). Chromium–molybdenum steel (0·35% C, 1% Cr, 0·15% Mo), quenched in oil at 850° and tempered at 650° C., will fracture along cracks known as the 'rotten wood' type. Examination of suitably prepared surfaces of the metal show the presence of inclusions and a band structure, which are the cause of this type of fracture.—T. E. D.

CORROSION

Experimental Approach to the Problem of Tuberculation by Waters. R. S. Thornhill. (*Chem. Ind.*, 1951, Dec. 31, 1201–1207). Tuberculation is typical of soft waters. Solutions of Calgon (sodium hexametaphosphate) and Micromet (sodium calcium hexametaphosphate) when fed into a stream of water were effective in correcting tuberculation, especially when the water flow was turbulent.—B. G. B.

Modern Engineering Aspects of Water Supply. R. W. G. Clerke. (*Manchester Assoc. Eng. Advance Copy*, Jan. 11, 1952). While the paper is mainly concerned with water supply and conservation, the external protection of steel mains is also dealt with. A copper/copper-sulphate half cell for surveying the earth to soil potential and a magnesium anode protective installation are described.—R. A. R.

Aerobic Microbiological Corrosion of Water Pipes. E. Olsen and W. Szybalski. (*Acta Chem. Scand.*, 1949, **3**, 1094–1116: *Corrosion*, 1950, **6**, Dec., 405–414). The authors explain a theory of the corrosion of iron water pipes by the formation of 'tubercles' consisting mainly of hydrated iron oxides and containing iron bacteria surrounded by sheaths. The bacteria oxidize ferrous ions to ferric ions, thereby gaining the energy necessary for their metabolism. It is suggested that: (1) Through their growth on limited regions of the iron surface the iron bacteria form 'differential aeration cells' causing electrochemical corrosion; (2) the felt-like structure of the bacterial sheaths causes mechanical strengthening of tubercles; (3) with increasing thickness of tubercles with or without the collaboration of the bacteria the tubercles become more anaerobic, thus increasing the difference of potential between the iron surface under and outside the tubercle. Corrosion experiments using sterile water with and without inoculation with iron bacteria, microscopic observations, and experiments with a differential aeration cell are shown to confirm points (1) and (2). Iron bacteria play only a minor part in the establishment of anaerobic conditions under tubercles during the main period of corrosion.—O. H. G.

Corrosion Problems Arising from Water in Chemical Industry. U. R. Evans. (*Chem. Ind.*, 1951, Dec. 31, 1193–1200). Although dissolved oxygen can be regarded as an inhibitor for aluminium and stainless steels it accelerates the corrosion of iron unless another inhibitor is present. Electrochemical action in water will usually cause corrosion of iron if the anodic and cathodic products are freely soluble. The attack will stifle itself where one or other is sparingly soluble. Calcium bicarbonate is of limited use as an inhibitor for cooling systems. The necessity for adding sufficient amounts of anodic-type inhibitors is stressed. Methods of avoiding caustic cracking are discussed.—B. G. B.

Tests on Heat-Resisting Cast Irons. M. M. Hallett. (*J. Iron Steel Inst.*, 1952, **170**, Apr., 321–329). [This issue].

ANALYSIS

Colorimetric Determination of Aluminium in Iron Ore and Steel. J. L. Kassner and Mary A. Ozier. (*Anal. Chem.*, 1951, **23**, Oct., 1453–1455). The method makes use of the fact that hydrogen peroxide will form peroxidized compounds with titanium, vanadium, etc., but will not oxidize iron in the ferrocyanide complex. Aluminium quinolate has been quantitatively extracted with chloroform from ammoniacal solutions containing tartrate, cyanide, and hydrogen peroxide at *p*H 9. The method makes possible the determination of aluminium in the presence of copper, nickel, zinc, cadmium, iron, titanium, vanadium, zirconium, uranium, manganese, chromium, molybdenum, and tin.—J. B. B.

Phosphoric Acid Interference with Quantitative Iron Precipitation by Ammonium Hydroxide. G. Norwitz and S. Tudor. (*Amer. Foundryman*, 1951, **20**, Aug., 62). From a published claim that iron salts are partially soluble under the conditions used for the precipitation of magnesium as magnesium ammonium phosphate, it appeared that phosphoric acid would hinder the precipitation of iron by ammonium hydroxide. Subsequent investigations proved this to be true, and that the more phosphoric acid and ammonium hydroxide present the greater would be the interference.—E. J. D. S.

Determination of Vanadium in Ferro-Vanadium. (*J. Iron Steel Inst.*, 1952, **170**, Apr., 343–347). [This issue].

Determination of Impurities in Electroplating Solutions. XXI. Traces of Lead in Zinc Plating Baths. E. J. Serfass and Mary H. Perry. (*Plating*, 1951, **38**, May, 473–476). A method of determining lead in zinc-plating baths is described. The lead is separated from interfering ions by extraction with a carbon tetrachloride solution of dithizone in the presence of potassium cyanide.—A. G.

ECONOMICS AND STATISTICS

General World Situation. G. W. Wolf. (*U.S. Steel's Policies on Costs, Prices, Plants, Productivity*, 1950, Jan. 24, 57–62). The world steel situation from 1870 onwards is reviewed. Today, lack of integration in the economy of the European countries holds back development and efficiency in those countries. The American steel industry is not similarly restricted.—T. E. D.

Italy's Steel Industry: Programme of Reorganization and Development. (*Iron Steel*, 1951, **24**, Dec., 545–546). This article reviews the economics of the Italian steel industry with special reference to the programme of reorganization and development undertaken since 1945.—G. F.

Iron and Steel Industry in India. P. E. Mehta. (*Metal Progress*, 1951, **60**, Oct., 93–96, 218, 224). The present state of development, and the sources of raw materials are discussed.—J. P. S.

The Scarcity of Some Strategic Metals and the Possibilities of Overcoming the Problem. E. M. A. Lips. (*Metalen*, 1951, **6**, Nov. 30, 422–427). [In Dutch]. The work of the International Materials Conference is outlined and some examples of the changes in composition made to effect savings are given. Several compositions of free-machining and heat-resisting steels are surveyed.—R. S.

MISCELLANEOUS

Scope of Activity of the Industrial Management Department of a Large Ironworks. W. Laermann. (*Stahl u. Eisen*, 1951, **71**, Sept. 27, 1044–1049). The organization and functions of the industrial management department of an integrated ironworks are discussed. Its principal tasks concern working time, output, etc., materials management, and central operational statistics as well as technical costing.—J. P.

Modern Research: Its Contributions. R. E. Zimmerman. (*Business, Big and Small, Built America*; United States Steel Corp., 1950, Apr., 25–43). Several developments are used to illustrate the important part played by research. These include electrolytic tinning, various heat-treated steels, high-strength low-alloy steels, stainless steels, and seamless pipe. A study of ore-beneficiation is in progress.—T. E. D.

Metallurgical Progress. L. Sanderson. (*Steam Eng.*, 1952, **21**, Jan., 128–130). Zirconium metal is now being produced in England. Its use in plant construction and the production of ductile cast iron is reviewed. Owing to the scarcity of alloying materials boron steels are being reinvestigated. Low-carbon (0·03% C) stainless steels are also receiving attention. The use of the 'turbo hearth' in steelmaking and cerium to improve the tensile strength of iron castings is also reported.—B. G. B.

Vignettes of Stages in the Production and Use of Metals. F. T. M. White. (Australian Inst. Met.: *Australasian Eng.*, 1951, Sept. **7**, 97–106). The author shows how civilization has developed very largely on a metallic basis, through the medium of implements and instruments, machinery and transport, communication, etc. The historical development of prospecting, mining, mineral dressing, and the science of metallurgy are outlined.—P. M. C.

Colour Codes and Identification Numbers for Steel. J. Krämer. (*Technik*, 1951, **6**, Oct., 445–446). The article summarizes the decisions of the Standardisation Committee of the Technical Board of the East German Republic, issued under No. TGL 2700 00.02.—J. G. W.

Oxygen Our Helper and Enemy. A. Bichler. (*Hutnik*, (Prague), 1951, **1**, No. 9, 188–189). [In Czech]. Advantageous uses and detrimental effects of oxygen in metal production are discussed and the mode of operation of the Kapica expansion turbine as an oxygen generator is described.—F. F.

Radioactive Isotopes—Some Applications in the Metal Industry. K. Fearnside. (*Metal Ind.*, 1951, **79**, Nov. 16, 415–418). A general description is given of some typical applications of radioactive isotopes, both in research and in industry. These include the investigation of the mechanism of chromium electrodeposition, and of friction and wear between metal surfaces.—P. M. C.

Water Pollution by Industry. D. F. Othmer, M. D. Weiss, and R. S. Aries. (*Mech. Eng.*, 1951, **73**, Sept., 706–708). The paper is a summary of the findings of a survey of state legislation and regulations in the U.S.A.—D. H.

Buildings Destined to House Continuous Strip Mills in France. A. Bera. (*Ossature Métallique*, 1951, **16**, Dec., 583–588). An illustrated description is given of the buildings for the continuous strip mills now in construction in France.

Heating and Ventilating of Metallurgical Works. J. E. Lafon. (*Mét. Constr. Mécan.*, 1951, **83**, Sept., 677–681; Oct., 759–761). Conditions of comfort in terms of temperature and ventilation, and methods of local and central heating are discussed in a non-technical manner. Methods of conserving heat in buildings are briefly reviewed.—R. S.

BOOK NOTICES

BASHFORTH, G. REGINALD. "*The Manufacture of Iron and Steel.*" Volume Two, "*Steel Production.*" 8vo, pp. viii + 461. Illustrated. London, 1951: Chapman and Hall, Ltd. (Price 45*s.*)

There has long been a deficiency among British publications of metallurgical textbooks expressly designed for students. This has been especially so in process metallurgy. Most modern books on process metallurgy are specialized, whereas for the student one wants a comprehensive text embracing a whole field, such as the mechanical working of metals, or the production of non-ferrous metals, or of iron and steel.

In particular, it is surprising how such an important domestic industry as iron and steel manufacture has been neglected as a subject for a textbook. As far as the reviewer is aware, until the issue of the present work by G. R. Bashforth, there had been no worthwhile British book since the nineteen-twenties, when the classical "Blast-Furnace Practice," by Clements, and the most recent edition of "The Metallurgy of Steel," by Harbord and Hall, appeared.

Volume I of Bashforth, dealing with iron production, was published in 1948. In volume II the whole field of steel production is covered. It has been the author's intention to produce a work suitable both for the general student of metallurgy and as "a handy reference book for the busy industrialist." In some respects it is unfortunate that the work has been published in two volumes, for there is no doubt, in the reviewer's opinion, that it would have had a greater appeal to students if issued as one volume, even had this necessitated compressing some of the present material.

Volume II is indeed comprehensive. In addition to the Bessemer, open-hearth, and electric steelmaking processes, the author describes side-blown converter practice, modification of steelmaking processes, and blister, shear, and crucible steel. Further, there are chapters on open-hearth fuels, ingots and ingot production, steelworks instruments, the manufacture of special steels, and steelworks refractory materials.

Actually, there are three chapters on the Bessemer process. In the first the process is surveyed, while the other two chapters are devoted to the acid and basic processes, respectively. Naturally the treatment of the open-hearth process is more detailed. Again, a preliminary review is followed by a fairly detailed discussion of open-hearth fuels and then, before the separate chapters on the acid and basic processes, there is a chapter on the construction of the furnace.

The book certainly presents a good general account of the manufacture of steel, and the chemistry of each process is suitably explained, although there is not sufficient physical chemistry for the advanced student. No attempt has been made, for example, to base the chemistry on free-energy considerations. Further, it does appear that the chemistry of deoxidation and, in particular, chemical comparison of different elements for deoxidation have to some extent been neglected. It is also a pity that it has not been possible to discuss the use of oxygen in the open-hearth and arc furnaces. Incidentally, "Metallurgical Calculations," 1907, by Richards, is given among the references, whereas "Metallurgical Problems," 1943, by A. Butts, would surely be more appropriate.

In conclusion, it should be emphasized that the book covers a broad field in an able manner. It is well written and pleasingly produced. It can be recommended as a sound textbook for students and as a useful source of information for others generally interested in the subject of steelmaking. The book will certainly fill a gap in metallurgical literature in this country.—A. R. BAILEY

"*Further Laboratory and Workshop Notes.*" A second selection reprinted from the *Journal of Scientific Instruments*, compiled and edited by Ruth Lang for the Institute of Physics. 8vo, pp. xii + 290. Illustrated. London, 1951: Edward Arnold and Co. (Price 28*s.*)

This book comprises a selection of 124 notes from the *Journal of Scientific Instruments*. A very wide field is covered, the book being divided into seven sections under the following headings: Graphs and Drawings; Optical Devices and Techniques; Devices for Liquids and Gases; Heat, Thermometry and Furnaces; Laboratory and Workshop Tools, Processes and Devices; Vacuum and Pressure Techniques and Devices; Electrical Devices and Ancillary Equipment and Techniques. Several of the notes, at least, are likely to be of direct interest to metallurgists. In particular, Construction of Laboratory Electric Furnaces and Available Materials, by L. Walden, pp. 74–85, and Glass to Metal Seal Design, by W. J. Scott, pp. 176–198, are worthy of mention.

The standard of the notes is high and will need no recommendation to those familiar with the *Journal of Scientific Instruments*. It is obviously convenient for the laboratory worker and technician to have this selection combined and indexed in one handy volume.—A. R. BAILEY.

HAUFE, WILLI. "*Schnellstähle und ihre Wärmebehandlung.*" 8vo, pp. 276. Illustrated. München, 1951: Carl Hanser Verlag. (Price DM 29.–)

This book will be a welcome addition to users of high-speed steel in that it collects together under one cover a mass of information concerning the composition of high-speed steels and their fabrication into turning tools, twist drills, cutters, and the like. It does not, however, deal with the actual manufacture of high-speed steel.

The book is divided into seven sections. Section A deals with the historical development of high-speed steels, and shows in a series of tables the change in composition commencing with the plain carbon crucible steel of 1860 and concluding with the compositions of German high-speed

steels of 1950. Section B deals with the *modus operandi* of high-speed cutting tools, and gives particulars of the temperature of tool noses while actually at work, of the hardness of high-speed steels at elevated temperature, and similar data, all of which is of direct interest to metallurgists and engineers. Probably the most interesting part of the whole book is Section B, sub-section IV, which considers the effects of chemical composition, under 13 different headings, namely, carbon, tungsten, molybdenum, vanadium, chromium, cobalt, aluminium, titanium, boron, tantalum and niobium, uranium, beryllium and zirconium, and nitrogen. Section C, concerned with the finish-forging and heat-treatment of high-speed steels, contains a lot of useful data particularly concerning heating times during forging, rolling, annealing, hardening, and tempering. One sub-section is devoted to a consideration of surface reactions during reheating under three headings, namely, scaling, decarburization, and carburization. The users' practical requirements are particularly well catered for, and complete particulars are given about forging, annealing in order to increase machinability and to remove internal stresses, and about hardening and tempering. A number of pages are also devoted to surface treatments for improving the efficiency of tools, namely, chromium plating, nitriding, and treatment in an atmosphere of steam. A sub-section is also devoted to furnaces and pyrometry.

Section D covers the brazing and welding of high-speed steel to a cheaper base. The testing of high-speed steel by the user is dealt with in section E, the choice of suitable high-speed steels in section F, and future developments in section G. Unfortunately no reference is made to tungsten carbide tools, an omission which tends to make the book somewhat unreal, but it is nevertheless a worthwhile publication.—J. FERDINAND KAYSER

NEW PUBLICATIONS

AMERICAN INSTITUTE OF STEEL CONSTRUCTION. "*Steel Construction.*" A Manual for Architects, Engineers, and Fabricators of Buildings and Other Steel Structures. 5th ed., 12th printing. 8vo, pp. 431. Illustrated. New York, 1951 : The Institute. (Price $2)

ANGLO-AMERICAN COUNCIL ON PRODUCTIVITY. "*Coal.*" La. 8vo, pp. 107. Illustrated. London, 1951 : Anglo-American Council on Productivity. (Price 3*s.* 6*d.*)

ANGLO-AMERICAN COUNCIL ON PRODUCTIVITY. "*Productivity Report : Education for Management.*" Report of a visit to the U.S.A. in 1951 of a Specialist Team concerned with Education for Management. 8vo, pp. xii + 86. Illustrated. London, 1951 : The Council. (Price 4*s.* 6*d.*)

BRITISH STANDARDS INSTITUTION. "*British Standard Mechanical Tests for Metals (excluding Welds).*" B.S. Handbook No. 13, 1951. 8vo, pp. iv + 243. Illustrated. London, 1951 : The Institution. (Price 17*s.* 6*d.*)

BRITISH STANDARDS INSTITUTION. B.S. 970 : 1947, Addendum No. 1, November, 1951. "*Emergency Specifications for Case-Hardening Steels.*" 8vo, pp. 12. London : The Institution. (Price 1*s.*)

BRITISH STANDARDS INSTITUTION. B.S. 1000, vol. 2, part 2, Addendum. "*Universal Decimal Classification. Index.*" Vol. 2, part 2, class 54, "*Chemistry, Crystallography, Mineralogy.*" La. 8vo, pp. 27. London, 1951 : The Institution. (Price 3*s.* 6*d.*)

BRITISH STANDARDS INSTITUTION. B.S. 1121 : Part 23 : 1951. "*Methods for the Analysis of Iron and Steel.*" Part 23. "*Manganese in Iron and Steel (Absorptiometric Method).*" 8vo, pp. 8. London : The Institution. (Price 1*s.*)

BRITISH STANDARDS INSTITUTION. B.S. 1804 : 1951. "*Parallel Dowel Pins (Steel).*" 8vo, pp. 12. Illustrated. London : The Institution. (Price 2*s.*)

EVRARD, RENÉ. "*Dom Nicolas Spirlet,*" Maître de Forge à Poix, au Châtelet et au Fourneau Saint-Michel. Préface de Paul Doat.. 4to, pp. 55. Illustrated. Liège, 1952 : Editions Solédi.

FUCHS, R., and H. BRADLEY. "*Welding Practice.*" Vol. I. "*Welding Methods and Tests.*" La. 8vo, pp. xii + 130. Illustrated. London, 1951 : Butterworth's Publications, Ltd. (Price 17*s.* 6*d.*)

GLAYMAN, J. "*Pour protéger les Métaux.*" 2nd ed. 8vo, pp. vi + 174. Illustrated. Paris, 1951 : Dunod. (Price 290 fr.)

GUY, A. G. "*Elements of Physical Metallurgy.*" 8vo, pp. ix + 293. Illustrated. Cambridge, Mass., 1951 : Addison-Wesley Press, Inc. (Price $6.50)

HORN, HANS A. "*Brennschneiden (Autogenes und elektrisches Schneiden).*" 8vo, pp. vi + 161. Illustrated. Berlin, Göttingen, Heidelberg, 1951 : Springer. (Price DM 12.60)

"*Hütte.*" Taschenbuch für Betriebsingenieure (Betriebshütte), 4. neu bearbeitete und erweiterte Aufl., herausgegeben vom Akademischen Verein Hütte e.V. in Berlin und Dr.-Ing. Hans Rögnitz. Erster Teil, pp. 426. Illustrated. Berlin, 1951 : Verlag von Wilhelm Ernst & Sohn. (Price DM 36.–)

KRAUSE, HUGO. "*Metallfärbung.*" 3rd ed., pp. 166. München, 1951 : Carl Hanser Verlag. (Price DM 12.50)

LANGFORD, KENNETH E. "*Analysis of Electroplating and Related Solutions.*" 8vo, pp. xi + 369. Illustrated. Teddington, Middlesex, 1951 : Electroplating and Metal Finishing. (Price 52*s.*)

LINFORD, A. "*Flow Measurement and Meters.*" 8vo, pp. 336. Illustrated. London, 1951 : E. and F. Spon, Ltd. (Price 30*s.*)

LUMSDEN, JOHN. "*Thermodynamics of Alloys.*" Institute of Metals Monograph and Report Series No. 11. 8vo, pp. xv + 384. Illustrated. London, 1952 : The Institute of Metals. (Price 35*s.*)

MCDONALD, DONALD. "*Percival Norton Johnson.*" The Biography of a Pioneer Metallurgist. 8vo, pp. 224. Illustrated. London, 1951 : Johnson Matthey and Co., Ltd.

MARTIN, J. L., and M. SERVENT. "*Le Fondeur.*" 8vo, pp. 230. Illustrated. Paris, 1951 : Editions Eyrolles.

MILEK, JOHN T. "*Guide to Foreign Sources of Metallurgical Literature.*" 4to, pp. x + 95. Pittsburgh, Pa., 1951 : Richard Rimbach Associates.

MINISTRY OF LABOUR AND NATIONAL SERVICE. "*Dust in Steel Foundries.*" Second Report of a Committee appointed to consider methods of preventing the production or the inhalation of dust and the possibility of reducing the use of materials containing free silica in steel works. 8vo, pp. 83. Illustrated. London, 1951 : H.M. Stationery Office. (Price 3*s.* 6*d.*)

"*Oberflächenbehandlung in der Blechverarbeitung, Berichte Folge 2.*" Herausgegeben von der Forschungsgesellschaft Blechverarbeitung e.V., Düsseldorf. Pp. 76. Illustrated. Düsseldorf, 1951 : Forschungsgesellschaft Blechverarbeitung e.V. (Price DM 6.50)

ORGANISATION FOR EUROPEAN ECONOMIC CO-OPERATION. "*Coal and European Economic Expansion.*" 8vo, pp. 68. Paris, 1952 : Organisation for European Economic Co-operation.

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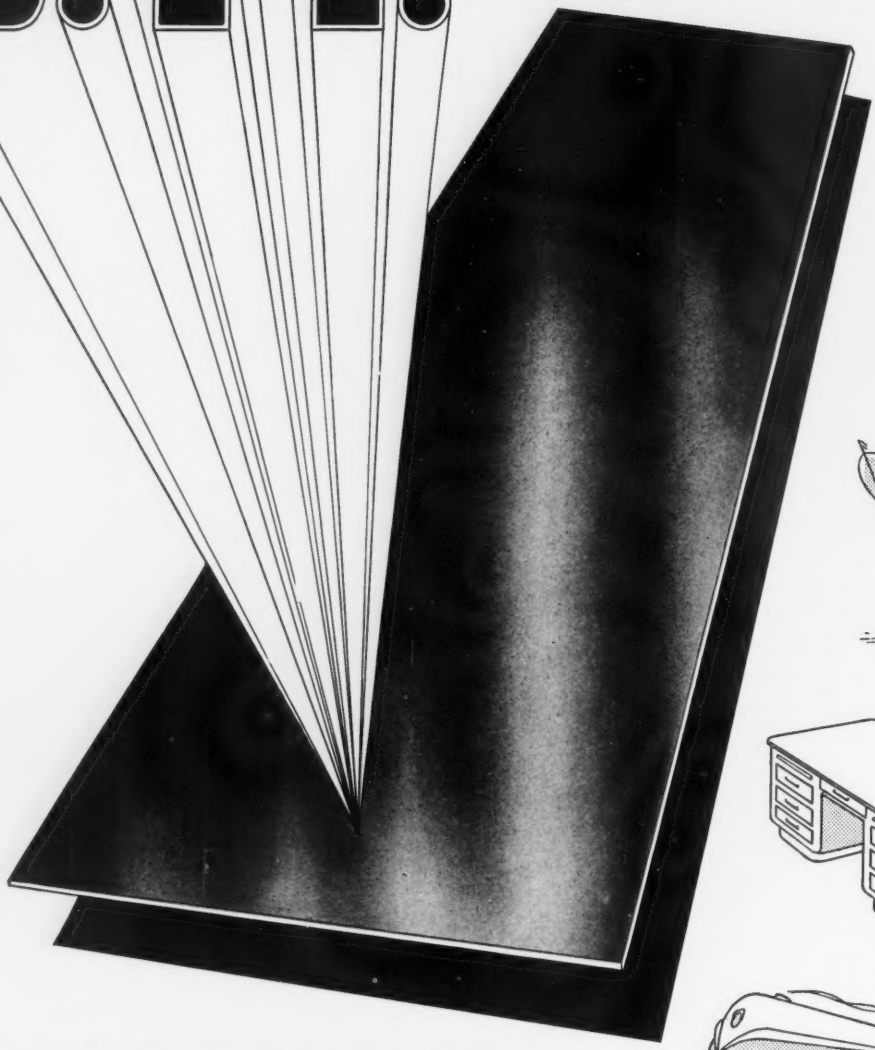

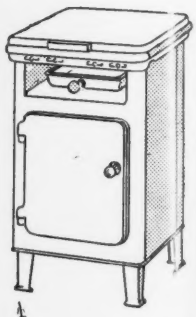

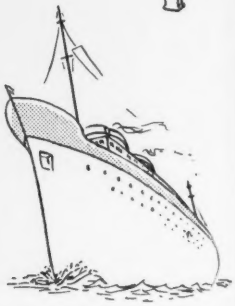

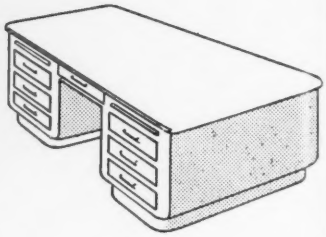

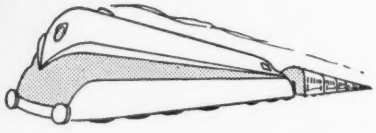

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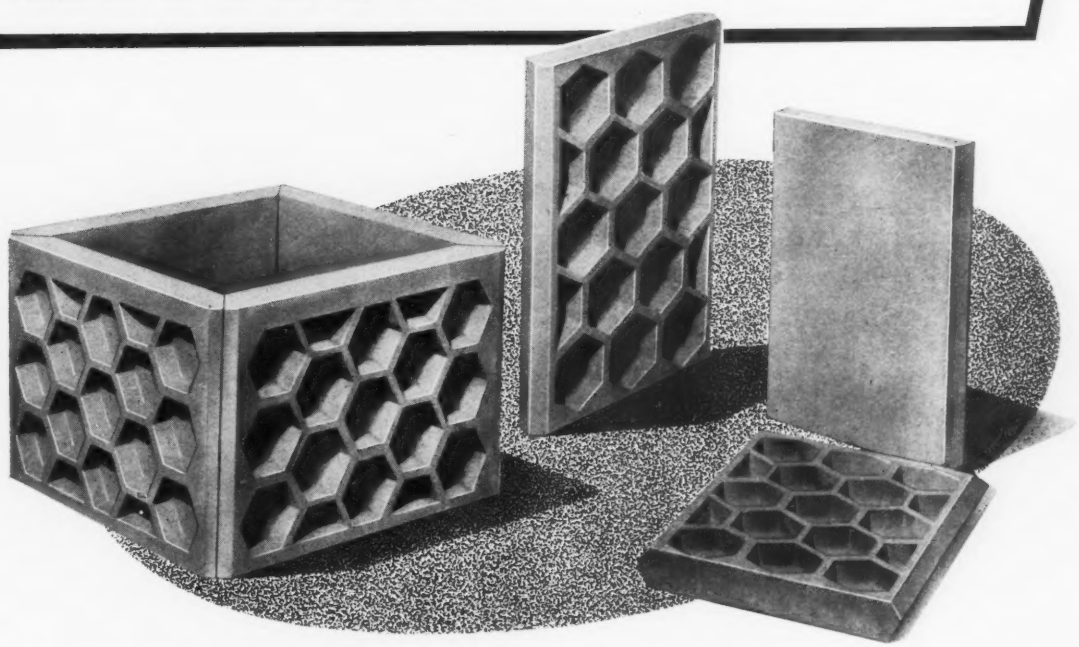

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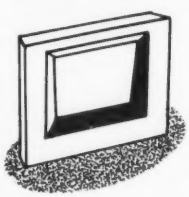

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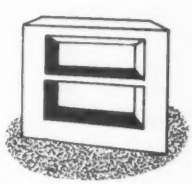

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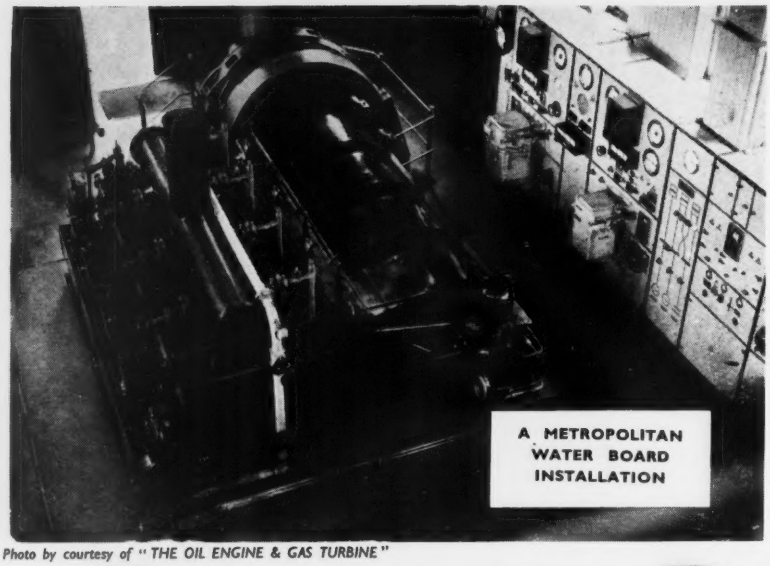

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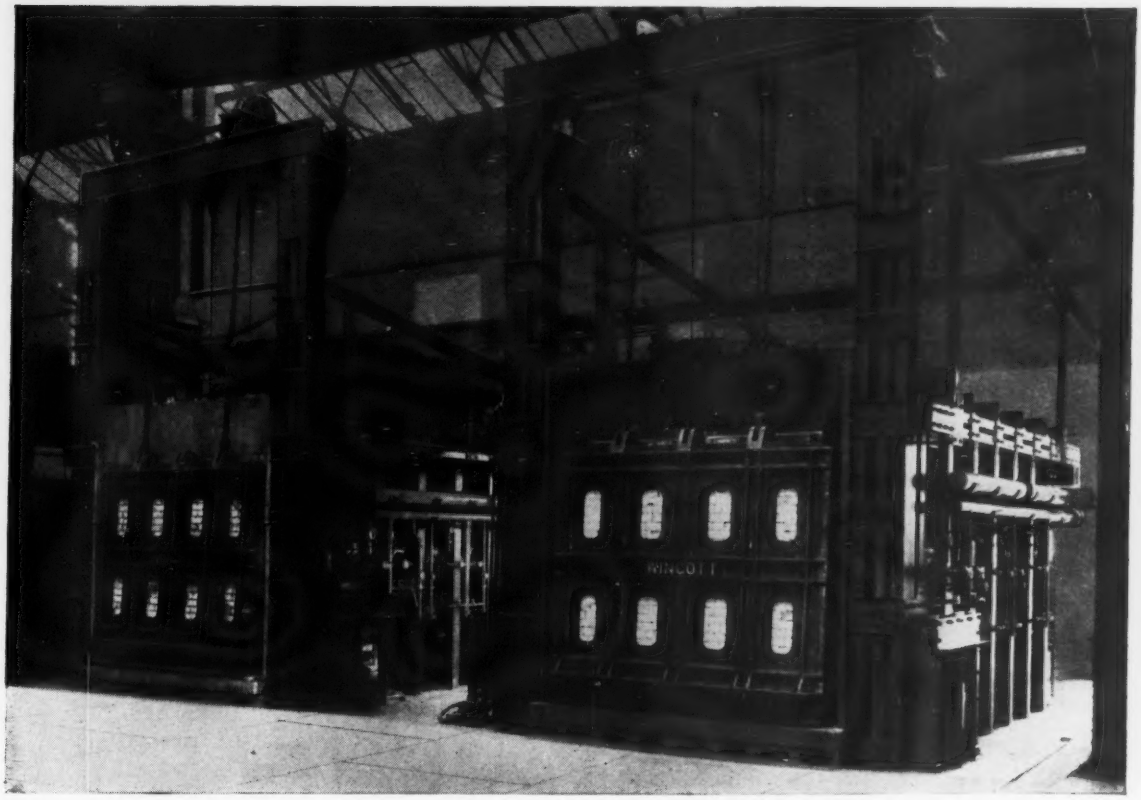

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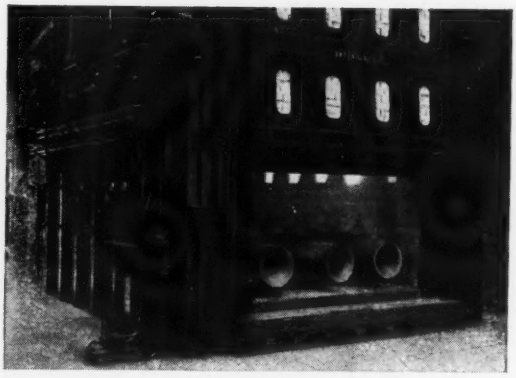

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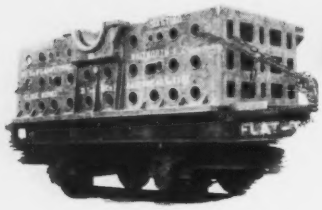

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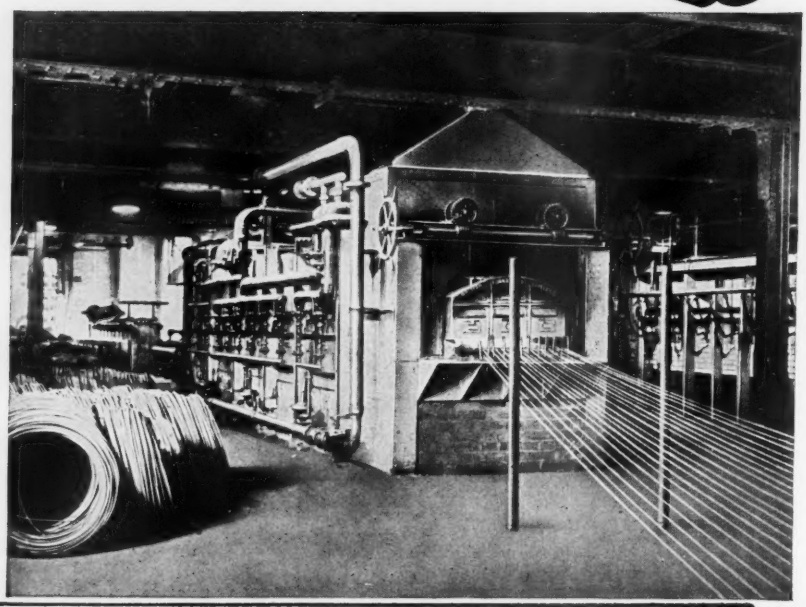

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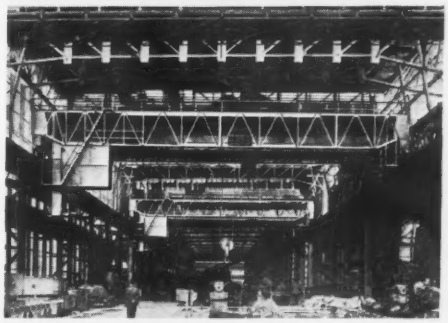

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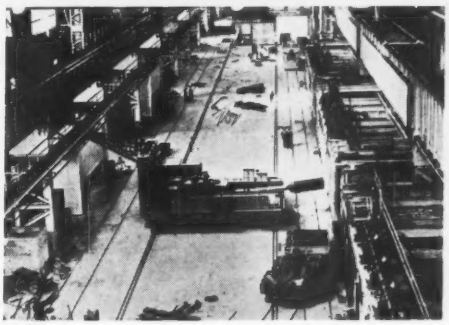

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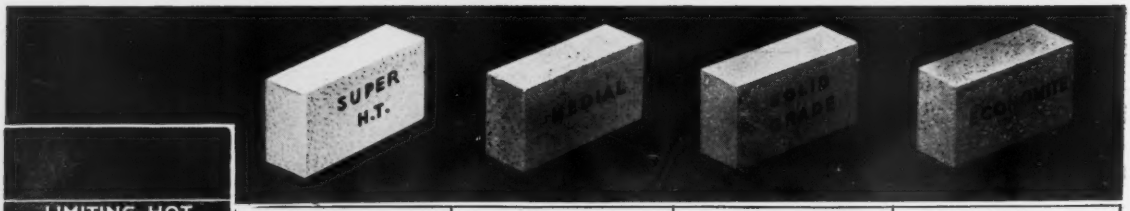

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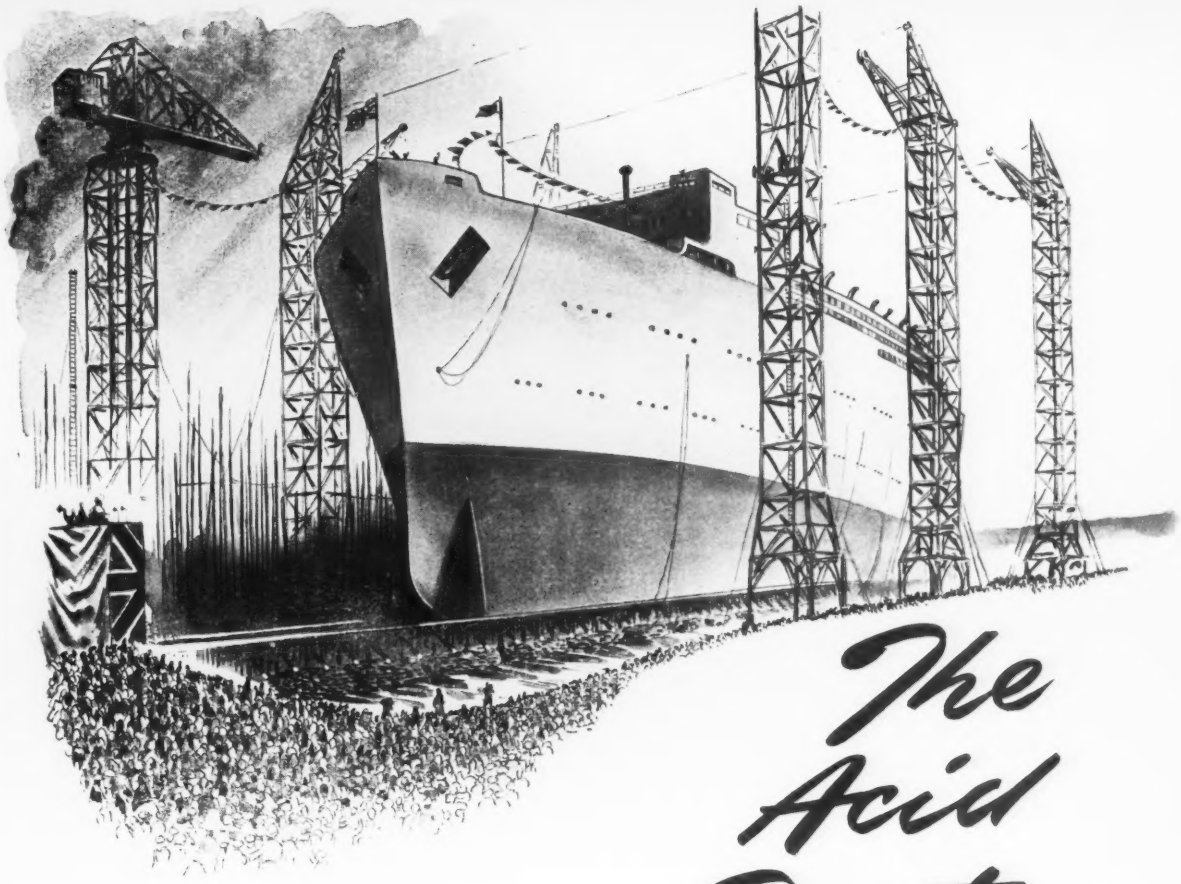

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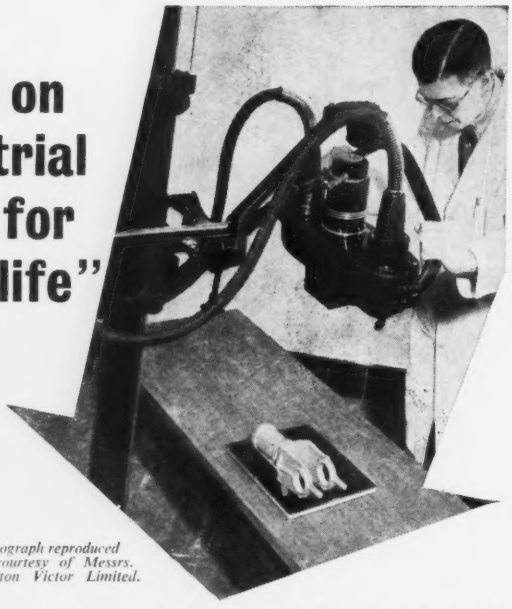

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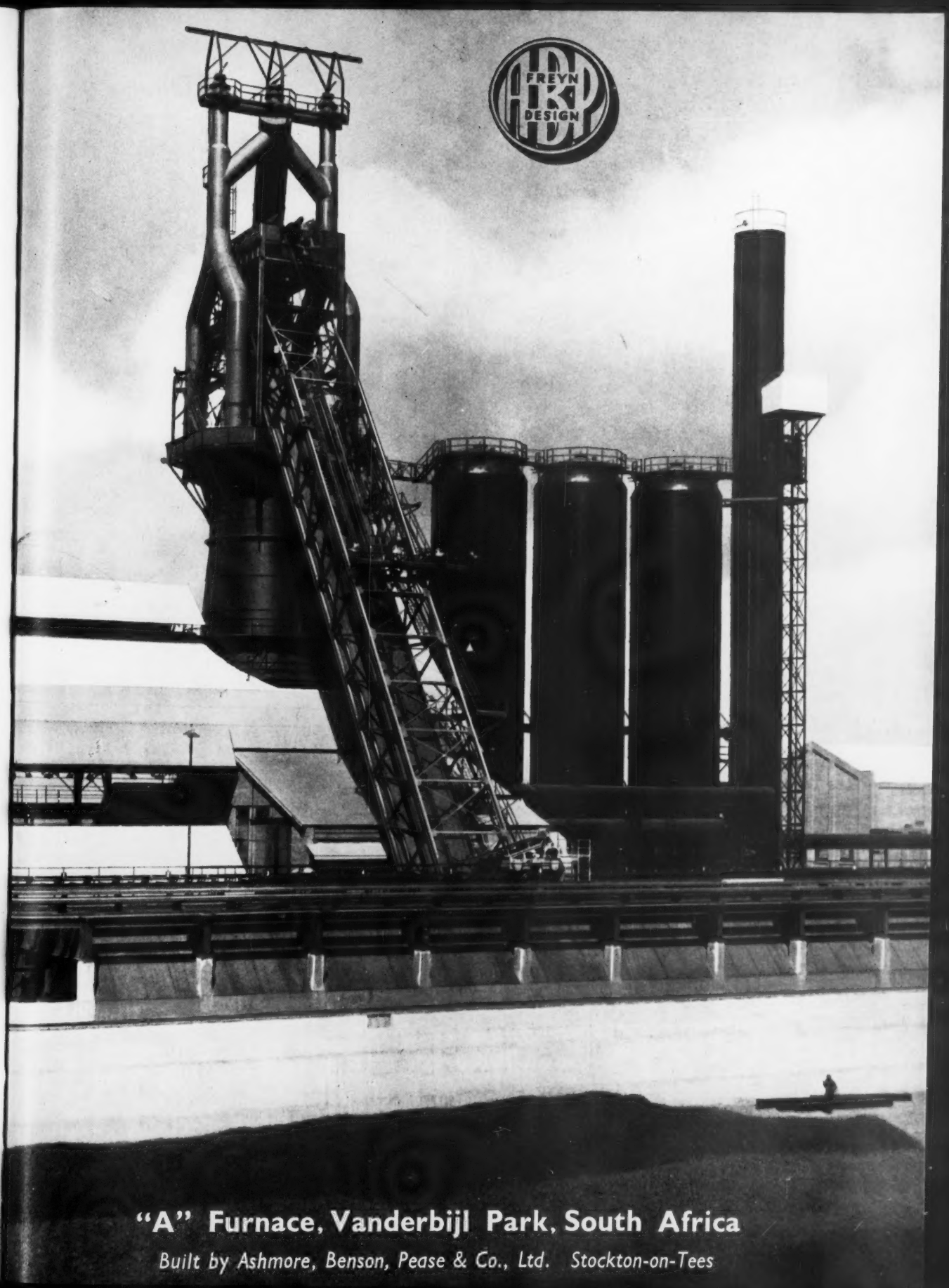

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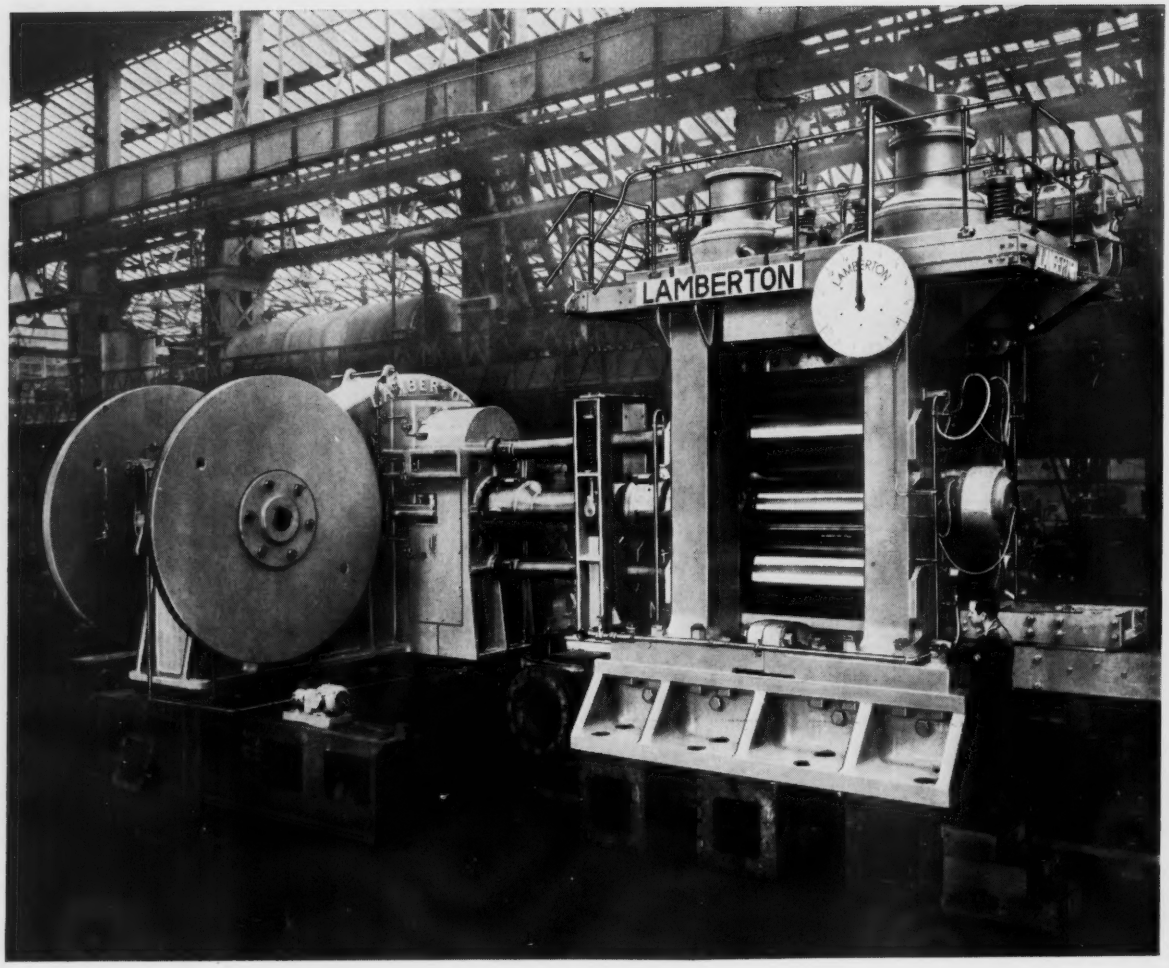

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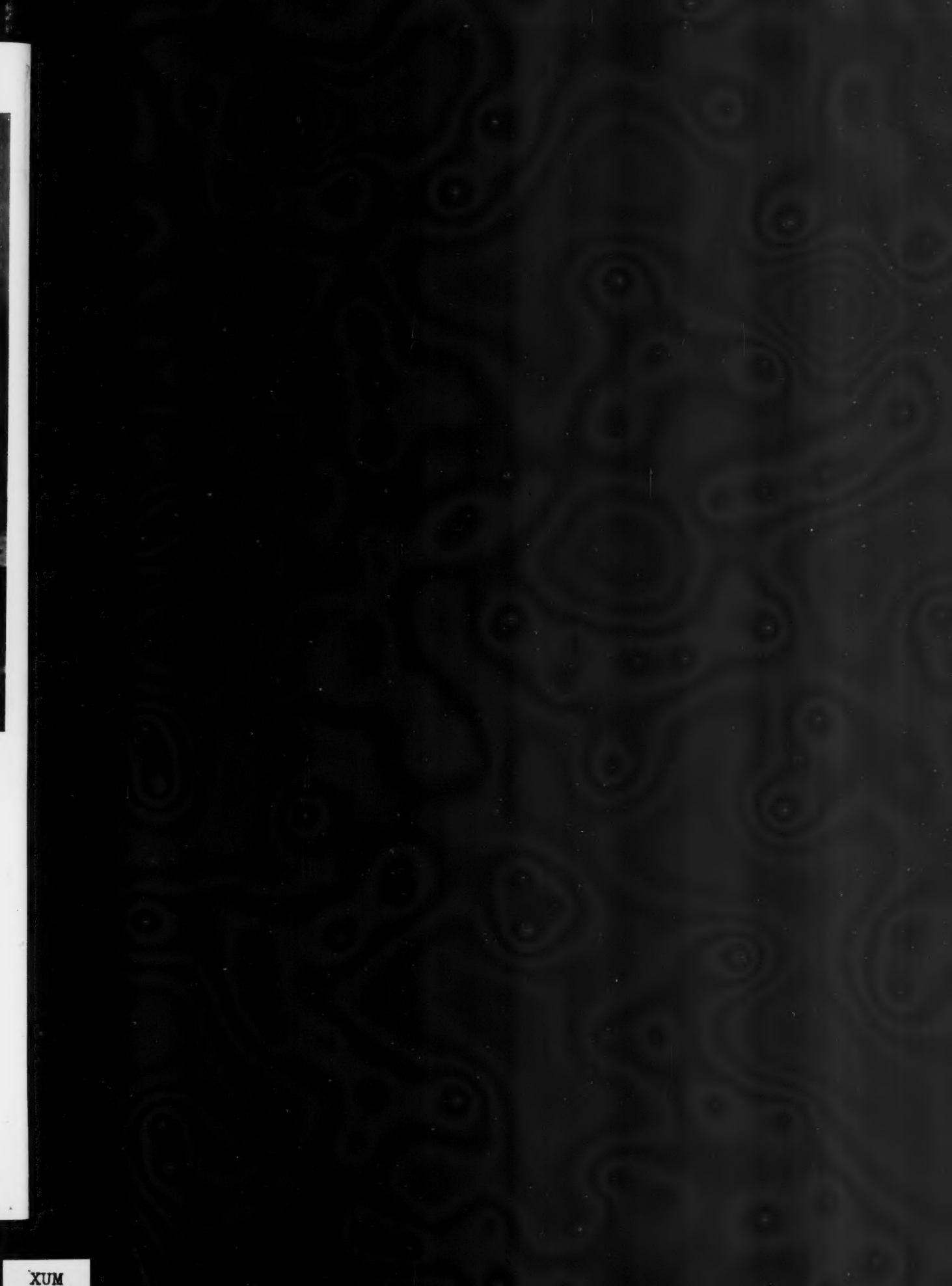

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